ORAU Team **NIOSH Dose Reconstruction Project** Technical Basis Document for the Fernald Environmental Management Project (FEMP) – Site Description	Document Number: ORAUT-TKBS-0017-2 Effective Date: 05/20/2004 Revision No.: 00 Controlled Copy No.: _____ Page 1 of 83
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ACRONYMS AND ABBREVIATIONS

AEC	Atomic Energy Commission
ALAP	as low as practicable
AMS	air monitoring station
BZ	breathing zone
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
FEMP	Fernald Environmental Management Project
FEMP	Feed Material Production Center
GA	general area
MAC	maximum allowable concentration
MCW	Mallinckrodt Chemical Works
MTU	metric tons uranium
NIOSH	National Institute for Occupational Safety and Health
NPR	New Production Reactor
NTS	Nevada Test Site
OEPA	Ohio Environmental Protection Agency
PCB	polychlorinated biphenyl
PHA	preliminary hazard analysis
POOS	plutonium out of specification
RMI	Reactive Metals, Inc.
RTS	Radon Treatment System
R-O-R	reduction-oxidation-reduction
SERF	Slightly Enriched Recovery Facility
STC	strong tight container
TBD	technical basis document
TRU	transuranic
USC	United States Code
WL	working level

2.0 SITE DESCRIPTION

This Technical Basis Document (TBD) of the Fernald Environmental Management Project (FEMP) site profile describes the facilities and processes that occurred at FEMP over the life of operations and the radioactive sources associated with those facilities and processes. This TBD provides the technical basis of the FEMP site, facilities and processes for the purpose of supporting estimates of occupational worker radiological dose based on exposure to the conditions and materials in the facilities.

Technical Basis Documents and Site Profile Documents are general working documents that provide guidance concerning the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist NIOSH in the completion of the individual work required for each dose reconstruction.

In this document the word “facility” is used as a general term for an area, building or group of buildings that served a specific purpose at a site. It does not necessarily connote an “atomic weapons employer facility” or a “Department of Energy facility” as defined in the Energy Employee Occupational Illness Compensation Program Act of 2000 [42 U.S.C. § 7384l (5) and (12)].

For the National Institute for Occupational Safety and Health (NIOSH) dose reconstruction program and this TBD, the following criteria are applicable:

- TBDs are being developed to support the radiation dose reconstruction efforts. Therefore, the only information included in this TBD is that which will aid the dose reconstructor in that effort.

- This TBD is structured to support dose reconstructions that require research and analyses that might include determining or assuming specific characteristics of the monitoring procedures; identifying events or processes that were unmonitored; identifying types and quantities of radioactive materials involved; evaluating production processes and safety procedures employed; and identifying potential locations and activities of exposed persons.

2.1 INTRODUCTION

The FEMP, formally known as the Feed Materials Production Center (FEMP), was a large-scale, integrated facility that produced uranium metal products (e.g., derbies, ingots, billets, and fuel cores) used as feed materials in U.S. Department of Energy (DOE) defense programs. The site production mission has ended and the site has been undergoing remediation and cleanup since 1989. The facility officially closed as a production facility in 1991 and DOE changed its name to Fernald Environmental Management Project (FEMP) to reflect the current mission of site cleanup and remediation. FEMP will be used throughout this TBD regardless of any reference to operational period of the Site. The descriptions in this TBD provide technical bases that the dose reconstructor can use to support historic dose reconstruction analyses, including situations for which monitoring data are unavailable and/or other methods might not be amenable for claimant dose reconstruction. For this purpose, this TBD compiles available and obtainable relevant operational radiological characterization data for FEMP facilities and processes that can be used as technical bases to describe specific radiological conditions that workers may have experienced during their tenure at the FEMP.

2.1.1 Site Background and History

The FEMP began operations at the Pilot Plant in 1951, and was fully operational by the end of 1954. Its primary function was to convert uranium ore concentrates and recycled materials to either uranium oxides or highly purified uranium ingots and billets for machining or extrusion into tubular forms of assorted uranium enrichment. These products were prepared for use as production reactor fuel cores and target fuel elements. In addition, small amounts of thorium were processed.

Uranium metal production peaked in 1960 at approximately 10,000 metric tons uranium (MTU), and in 1964 began to decline to a low in 1975 of approximately 1,230 MTU. During the 1970s, consideration was given to closing the FEMP. From 1972 through 1979, the staffing level, which peaked at 2,891 in 1956, slowly declined from 662 to 538. In FY 1981, FEMP received direction to plan the restoration of the site to accommodate projected product requirements approaching the original production capacity. Significantly increased production levels, rapid staff buildup in many areas and implementation of a major facilities restoration program followed. Accomplishments since that time included production output of three times the 1979 level and a staff increase from 538 to more than 1,000.

The production of uranium metal at the FEMP ended in July 1989 to concentrate on site cleanup efforts. Current operations are completely dedicated to site remediation and restoration.

2.1.2 Site Location and Facilities

The FEMP is near the unincorporated village of Fernald in the Great Miami River Valley, about 20 miles northwest of Cincinnati in southwestern Ohio. The FEMP site covers an area of 1,050 acres. The production area encompasses approximately 136 acres in the center of the site.

Figure 2-1 shows the FEMP site in 2002. Historically, production area facilities included nine separate plants, the pilot plant, ancillary buildings, and administrative buildings that are connected with a network of roadways. These facilities, along with concrete storage pads, gravel ground cover, railroad access, sanitary landfill, and metal scrap piles, are surrounded by security fencing. Outside the 136-acre fenced production area, the Waste Storage Area includes six low-level radioactive waste storage pits, two earthen-bermed concrete silos containing K-65 residues (high specific activity radium-bearing residues), one concrete silo containing metal oxides, and all affected adjoining areas. This area also includes two fly ash piles approximately 3,000 feet south-southwest of the waste storage area, as well as the burn pit between Pits 3 and 4. Production operations were handled in Plants 1 through 9 and the Pilot Plant. Some of the plants and buildings that existed while the site was in operation no longer exist. As of 2002, Plants 1, 4, 5, 6, 7, and 9 have been dismantled, and others are in various phases of dismantlement or planning. The following sections provide a historical overview of the facilities and processes at the FEMP with respect to information and data to support the dose reconstruction efforts.

2.1.3 Site Operations

The FEMP used a wide variety of chemical and metallurgical process steps to support the primary mission of supplying metallic fuel cores for production reactors at Richland, Washington, and Savannah River, South Carolina. In addition, some metal was shipped directly to DOE facilities at Oak Ridge, Tennessee, and Rocky Flats, Colorado.

The first step in the FEMP production process was the purification of uranium. In the early years, the site processed uranium ore, including pitchblende ore from the Belgian Congo, through a series of chemical processes. Later, it extracted uranium from scrap metal or recycled material (e.g., floor

sweepings, dust collector and production residues) received from onsite operations and other DOE complex sites.

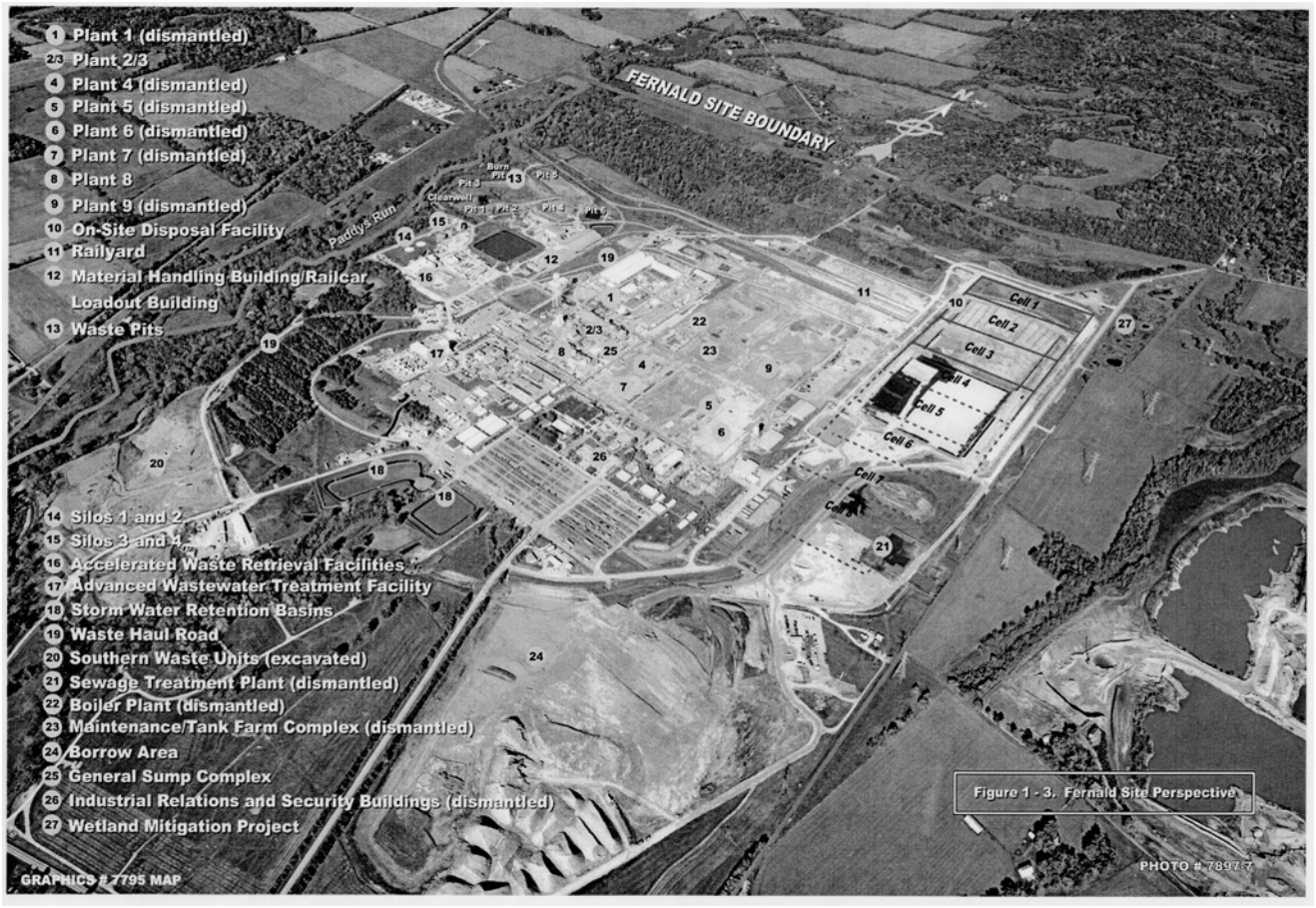

Figure 2-1. The FEMP Site (as of 2002).

FEMP uranium production began with ore concentrates, recycled uranium from spent reactor fuel, or various uranium compounds as feed materials. Impure starting material was dissolved in nitric acid to produce a crude uranyl nitrate solution (UNH) for solvent extraction purification. Purified UNH was concentrated by evaporation and thermally denitrated to uranium trioxide (UO_3), or orange oxide. Orange oxide was converted to uranium tetrafluoride (UF_4), or green salt, for reduction to metal. In addition, green salt was produced from uranium hexafluoride (UF_6) received from other DOE sites.

Uranium metal was produced by reacting UF_4 and magnesium metal in a refractory-lined reduction vessel. The uranium metal was shaped in forms called derbies, each weighing 136 to 168 kg. This primary uranium metal was remelted with scrap uranium metal to yield a purified uranium ingot that was extruded to form rods or tubes. Sections were cut and machined to final dimensions. These machined cores were shipped to other DOE sites for canning and final assembly into reactor fuel elements. Since the late 1960s, all cylindrical ingots were center drilled at FEMP and sent off the site for extrusion. Most of the extruded tubes were returned to FEMP for heat treatment and final machining before they were shipped for use at other DOE sites.

Periodically, small amounts of thorium were processed. Thorium production steps, in general, were similar to those followed in uranium production. Final products were purified thorium nitrate solution,

solid thorium compounds, or metal. Since 1972, the FEMP served as the thorium materials repository for DOE. Approximately two-thirds of the material in the repository was processed at the FEMP. The remainder originated at other DOE facilities.

FEMP supported the Richland N-Reactor by processing enriched uranium scrap residues generated during the metal production steps plus Purex UO_3 recycles. Enriched UF_6 was required to replenish the ^{235}U consumed in N-Reactor operations. All three material types were converted to UF_4, which was the starting point for metal production operations. Production of depleted uranium metal for the Savannah River Mark 31 stream, the Y-12 Plant, and Rocky Flats began with UF_4 from inventories.

The uranium processed was depleted, natural, or slightly enriched. The average content was close to natural uranium isotopic ratios. ^{235}U enrichments in raw materials ranged up to approximately 20%. However, the maximum product enrichment was 1.25% and the average product was slightly depleted. In general, 2% enriched uranium was the highest enrichment processed in significant quantities. Small quantities of fission products (e.g. ^{90}Sr, ^{137}Cs, and ^{99}Tc) and transuranics (e.g., neptunium, plutonium, and americium) were present in some recycled fuel. Raw feed materials containing very low concentrations of plutonium were used until as late as May 1986.

2.1.4 Presentation for Dose Reconstruction Purposes

The following sections present description of each individual FEMP facilities and their associated processes in a manner that aids the historic dose reconstruction analyses, making use of available and obtainable site data and information. Each facility description contains 1) the physical description of the facility and its associated processes and activities and 2) the description of the radiation sources that include the technical basis for internal dose and external dose reconstruction analyses specifically for the described facility. Section 2.5, "*FEMP Radioactive Materials and Characteristics*" provides the discussions, radiological data, and technical basis germane to all of the FEMP facilities. (i.e., the specific activity and isotopic composition of uranium, uranium compounds, and recycled uranium, along with the principal gamma and beta emissions from uranium and processed uranium compounds measured in field studies and isotopic information on thorium and thorium compounds and radon and thoron).

2.2 PRODUCTION FACILITIES ACTIVITIES AND PROCESSES

The FEMP was designed as a large-scale, integrated facility capable of converting uranium ore and recycled material into uranium metal through a series of chemical and metallurgical conversions. Production operations were conducted in Plants 1 through 9 and the Pilot Plant.

2.2.1 Pilot Plant – UF_6 to UF_4 Reduction Plant

The Pilot Plant was located in the southwest corner of the fenced production area and was completed during 1951 and had a ground floor area of 23,500 ft^2. Its principal function was to convert UF_6 to UF_4 for use in the metal production process. In addition, the Pilot Plant had the capability of coating by plasma spray the crucibles used for casting uranium metal. The principal functions of the Pilot Plant were:

- Reduction of UF_6 to UF_4 assaying up to 2.5% ^{235}U;
- Purification and conversion of thorium nitrate solution to various thorium compounds; and

- Miscellaneous operations for shot blasting uranium derby metal and plasma spray coating graphite crucibles.

This unit of the FEMP production complex had a wide range of chemical-metallurgical process equipment for the production of small quantities of uranium and thorium products. A variety of operations and assorted tasks occurred in this plant.

A considerable part of the metal produced at the FEMP was depleted uranium. The principal source for depleted uranium was the UF_6 tails, the byproduct from uranium enrichment at the gaseous diffusion plants.

2.2.1.1 Processes and Activities

The Pilot Plant converted gaseous UF_6 to solid UF_4 green salt. The UF_6 arrived in solid form in large cylinders. To produce UF_4, the UF_6 was first heated to form a gaseous compound and subsequently reduced to UF_4. Three autoclaves and twin tube reactors were operated using a distributed control system. The UF_6 flow rate from the autoclave to the reactor tubes was approximately 2,200 lb/hour (50 psig and 230ºF). Both reactor tubes operated in the ranges of 900°-1200ºF and 5-20 psig. Under these conditions, the facility was designed to produce 16 MTU per day at 100% on-stream factor. Enriched UF_6 assaying as much as 2.5% ^{235}U could be processed.

Other equipment was available for such operations as metallic shot preparation; plasma-spray coating of casting crucibles for controlling carbon pickup; shot blasting uranium derbies for removal of slag material; and salt-bath heat treating. Single uranium melts as large as 3 tons could be cast in the special 6 ft. diameter vacuum casting furnace.

Thorium ores, crushed thoria (powdery form of thorium dioxide) pellets, thorium oxalate, and other thorium materials were processed through the Pilot Plant thorium digestion and/or extraction system from about 1964 through 1980. These systems were used to produce a purified thorium nitrate solution that could be used as feed for the production of high-quality thorium compounds (thorium hydroxide) or metal. In addition, purified thorium nitrate solution was shipped as product. The digestion and extraction systems were not used continuously during the period they were in service. During some years the systems achieved throughput rates as high as 1 ton per day of purified thorium nitrate solution; in other years they operated periodically or not at all. Available production records indicate that 790.4 metric tons of thorium in the form of purified thorium nitrate solution were produced from 1966 to 1973. No production records have been located for other years. No production data are available for the digestion system.

The solvent extraction refining was followed by a multitank system for precipitation, several filters, and an oven-drying system to produce thorium oxalate, thoria gel (hydrated gel oxide), or thorium tetrafluoride. Metal was produced by further processing ThF_4 through atmospheric furnaces for dehydration and metal reduction, vacuum furnaces for dezincing, and all auxiliary systems. A portion of the integrated extraction-precipitation system converted impure thorium nitrate solution to a storable dried thoria gel product for future DOE requirements. Production records indicate that 809 thorium derbies weighing approximately 51 metric tons [total] of thorium metal were produced by this process between 1969 and 1971.

Production records also indicate that 492 metric tons of thorium as thoria gel were produced from 1966 to 1970. Production for 1964 and 1965 was estimated based on a linear extrapolation of the quantity produced in 1966 through 1970. The estimated total production from this process is 686 metric tons assuming linear production from 1964 to 1970. From 1977 through 1979, production

records indicate that 350 metric tons of thorium as thoria gel were produced by similar process for storage.

From 1971 through 1976, 153 metric tons of thorium as thorium oxalate were produced by the precipitation process at the Pilot Plant.

In 1966, thorium nitrate tetrahydrate crystals were produced during a short-term test by use of a Sandvik Water Bed Conveyor. Purified thorium nitrate tetrahydrate solution was boiled in a tank to a defined concentration. The molten salt was fed onto a water-cooled conveyor where it crystallized, and product was drummed at the end of the conveyor. A total of 425 kilograms of thorium as thorium nitrate tetrahydrate crystals was produced during this test.

2.2.1.2 Radiation Sources

Radioactive sources in the Pilot Plant were primarily uranium and "recycle uranium" that consisted of UF_6 and UF_4 powder with mixed enrichment from depleted to 2.5% ^{235}U by mass. Other radioactive sources included thorium metal and compounds.

Table 2-1a lists the measured airborne radioactive material concentrations for operations and locations at the Pilot Plant. Table 2-1b and 2-1c provide the estimated potential annual uranium and thorium intakes by Pilot Plant operation personnel by the years as projected based on the measured data, respectively.

Table 2-1a. Pilot Plant airborne radioactivity concentration by operation or location (year data taken as indicated).

Operation or location	Measured Avg. conc. α dpm/m^3	Conc. w/Respirators[a] Bq/ m^3
Pilot Plant – wet area (uranium) (1968 data)		
Breaking up UO_2 tubes and putting metal into 5-gal cans	643.3	2.14E-01
Pump 6 ft west of Declad tank where decladding was conducted	49.7	8.28E-01
Pump 4 ft east of tank	51.3	8.55E-01
Unloading UO_2 from declad tank (no respirator worn)	50.8	8.47E-01
Furnace Area (uranium) (1973 data)		
General area on top of furnace 2' south of cooling door	303.0	5.05E+00
General area south side of window to dumping tray	223.3	7.44E-02
BZ complete dumping cycle	670.0	2.23E-01
BZ dumping to take-out can	510.0	1.70E-01
BZ taking can out and putting empty can in	506.0	1.69E-01
BZ dumping tray removing full and replacing with empty	2030.0	6.77E-01
BZ changing trays from furnace to cooling	640.0	2.13E-01
Average uranium concentrations	516.0	7.77E-01
Thorium blending (thorium) (1968 data)		
Separating thorium material from filter press (respirator worn)	400	1.33E-01
Pump 4 ft north of press	22.2	3.70E-01
Pump 5 ft west of press	80.0	1.33E+00
Pump 7 ft west of blender	49	8.17E-01
Unloading thorium from blender	61	2.03E-02
Unloading thorium from blender into small press, pump 9 ft southeast of blender	200	6.67E-02
Continuous precipitation operation, reactor tank vented by 4-in. duct		
BZ small Oliver drum filter	48	8.00E-01

Operation or location	Measured Avg. conc. α dpm/m^3	Conc. w/Respirators[a] Bq/ m^3
Pump 5 ft north of reactor tank	15.1	2.52E-01
4 ft south of thorium filter press	23.8	3.97E-01
Operator churning precipitate through funnel with broom handle	82	2.73E-02
Dumping drums into digest tank		
Area background level	14.8	2.47E-01
Dumping two drums into port hole of tank (GA)	15.8	2.63E-01
Dumping thorium drums into tank (BZ)	76.2	1.27E+00
Removing dried thorium from oven		
Removing from oven #2, respirator worn (BZ)	84.5	2.82E-02
Pump above #2 oven doors (GA)	14.5	2.42E-01
Unloading oven #1, respirator worn (BZ)	218.1	7.27E-02
Pump 6 in. in front open door of 07 dryer oven as it is loaded with wet thorium gel	542.7	1.81E-01
Pump 6 in. in front open door of 07 oven as dried thorium gel is removed	1,032.0	3.44E-01
General area – Stokes furnace platform	478.2	7.97E+00
Extraction area		
Operators desk	6.7	1.12E-01
Northwest corner	175	2.92E+00
West wall	150	2.50E+00
General area(1969 data)		
D1-Platform	15	2.50E-01
Thorium dryer	19	3.17E-01
Mezzanine	15.5	2.58E-01
Chip burning in oxidation furnace		
Desk in west of furnace	135.5	2.26E+00
Pipe 4 ft east of enclosure	507	8.45E+00
Packing chip into furnace crucible	116.7	3.89E-02
Average thorium concentration	170.2	1.07E+00

[a] A Decontamination Factor (DF) of 50 for wearing respirator was applied to Breathing Zone (BZ) concentrations for selected process activities.

Table 2-1b. Projected annual uranium intake estimates for Pilot Plant workers.

Years	Adjustment Factors[a] 1968 Data	Adjustment Factors[a] 1973 Data	Average Uranium Conc. Bq/m^3	Average Annual Uranium Intakes Bq/yr[b]
1951-1954	0.43	0.3	2.87E-01	6.89E+02
1955-1964	1.42	1.0	9.52E-01	2.28E+03
1965-1966	1.29	0.9	8.60E-01	2.06E+03
1967-1968	1.0	0.7	6.68E-01	1.60E+03
1969-1972	0.0	0.0	0.0	0.0
1973	1.42	1.0	9.52E-01	2.28E+03
1974	0.0	0.0	0.0	0.0
1975	0.35	0.25	2.37E-01	5.69E+02
1976	0.0	0.0	0.0	0.0
1977-1978	0.35	0.25	2.37E-01	5.69E+02
1979	0.0	0.0	0.0	0.0
1980	0.35	0.25	2.37E-01	5.69E+02
1981-1983	0.0	0.0	0.0	0.0

Years	Adjustment Factors[a]		Average Uranium Conc. Bq/m^3	Average Annual Uranium Intakes Bq/yr[b]
	1968 Data	1973 Data		
1984	1.06	0.74	7.07E-01	1.70E+03

[a] The measured airborne radioactivity concentrations are adjusted for other years than the year in which the measurements are made, in accordance with the percentage of process system throughput capacity in one shift. In absence of specific throughput information, Appendix 2A is used as the default model for FEMP production rates for the derivation of the adjustment factors. The " *FEMP uranium emissions summary by plant*" in Appendix 2B is used to identify operating years. 1973 data were taken at the end of a campaign, since then, it is assumed that the measured concentrations were resulting from full system capacity.

[b] Radionuclide (e.g., Pu, Np, Tc and U isotopes) radioactivity fractions for recycled uranium is given in Table 2-54.

Table 2-1c. Projected annual thorium intake estimates for Pilot Plant workers.

Years	Adjustment Factor[a]		Average Thorium Conc. Bq/m^3	Average Annual Thorium Intakes Bq/yr
	1968 Data	1969 Data		
1964-1968	1.0	0.87	8.98E-01	2.16E+03
1969	1.14	1.0	1.03E+00	2.47E+03
1970	1.45	1.27	1.31E+00	3.14E+03
1971	0.18	0.16	1.63E-01	3.91E+02
1972	0.41	0.36	3.69E-01	8.86E+02
1973	0.15	0.13	1.35E-01	3.24E+02
1974	0.29	0.25	2.60E-01	6.24E+02
1975	0.01	0.01	9.16E-03	2.20E+01
1976	0.0	0.0	0.0	0.0
1977-1979	1.19	1.04	1.07E+00	2.57E+03

[a] The thorium concentrations were obtained by multiplying the uranium concentration estimates for a particular year by the thorium/uranium emission ratio using the emission rate estimates in Appendix 2B.

2.2.2 Plant 1 – Sampling Plant

The Sampling Plant was completed in 1953 with a ground floor area of 22,040 sq. ft. This plant supported operations throughout the site. Its principal capabilities were:

- Shipping, receiving, sampling and storing large amounts of depleted, normal, and enriched uranium materials in open and covered storage areas.
- Drying, crushing, milling, grinding and classifying feed materials for processing.
- Digesting enriched residues assaying 5% to 20% ^{235}U in geometrically safe equipment.
- Opening unirradiated fuel pins containing enriched uranium dioxide pellets.
- Reconditioning steel drums for reuse and baling deteriorated drums for salvage.

The Sampling Plant weighed and sampled FEMP-generated and offsite recycle materials using various equipment to establish nuclear materials control data for accountability and control of fissionable materials processed at the FEMP. All incoming receipts were verified using nondestructive testing in the isotopic verification facility. The isotopic verification of incoming enriched uranium materials began in April 1972. At one time, the principal function of the Sampling Plant was

to obtain representative samples of large quantities of incoming ore concentrates. In 1988, however, the primary function was to store recycle materials until they were required by other production plants. The available storage area was 43,100 sq. ft. of open pads in a fenced area.

2.2.2.1 Processes and Activities

The sampling operation included a number of supporting operations. Several large-scale systems existed for crushing, grinding, and blending solid materials. These systems had a combined capacity of more than 10 tons per hour. Major equipment included hammer mills, ring-roll mills, and falling-stream samplers. Some of this equipment was shielded for handling radioactive materials. Special dust collecting and ventilating equipment permitted the processing of toxic and radioactive materials. Enriched uranium slag and selected recycle materials were processed through a ring-roller mill for reuse in the production of uranium derby metal or for chemical processing to UO_3 in the refinery. This equipment could reduce particulate size to 95% minus 325-mesh at a rate of up to 9.1 tons per day.

A safe geometry digestion system provided a capability of safely processing enriched uranium materials assaying from 5% to 20% ^{235}U at a rate of about 100 kg per shift.

Other facilities were available for opening fuel rods containing enriched UO_2 pellets and powder, reconditioning steel drums, and scrap metal baling.

2.2.2.2 Radiation Sources

The principal types of radioactive materials received and sampled at the outset of Sampling Plant operations were:

- Q-11 material (code name for pitchblende), most of which was mined in the Belgian Congo. Because no processing was performed on this material before its receipt at the FEMP, it contained the equilibrium quantity of radium, thus requiring shielding against radiation during processing of the radium-bearing streams.

- Uranium in magnesium precipitate (MgX) resulting from a leaching process.

- Q-11 containing less than 25% uranium. This low grade Q-11 was processed in the Belgian Congo and production was discontinued about the time the refinery was ready for operation. Only small quantities were received.

- Black oxide derived from concentrating low-grade uranium ores of U.S. and Canadian origin.

- Uranium in sodium salt (NaX) resulting from precipitation of leach liquors (from low-grade U.S. or Canadian source uranium ores) with sodium hydroxide.

- Canadian ores that contained thorium. These ores started arriving in 1956 and reached large-quantity levels by June 1957.

- Uranium compounds of up to 5% enrichment. In 1965, the FEMP became the official receiving station for uranium compounds of up to 5% ^{235}U furnished by licensees. With the startup of enriched uranium operations in the refinery in 1966, more than 1,500 safe mass batches of up to 10% ^{235}U feed materials were prepared for drum digestion. This recycled uranium was known to contain traces of ^{237}Np, ^{238}Pu, and ^{239}Pu.

- Higher enrichment uranium compounds. In 1967, the isotopic level for the digestion operation was reduced to a maximum assay of 5% ^{235}U as a further nuclear safety measure. Feed materials in the 5% to 10% assay range were set aside for the Safe Geometry Digestion System that started up in 1970 to provide the capability of safely processing enriched uranium materials up to 10% ^{235}U. In subsequent years the range was increased to accept up to (but less than) 20% enriched material.

- Concentrate and residue drums. After the Mallinckrodt Chemical Works (MCW) Refinery was shut down in 1966, more than 20,000 drums of concentrates and residues were shipped to the FEMP and stored on the Plant 1 pad.

- Grand Junction, Colorado, shipments. Shipments of concentrates from Grand Junction, Colorado, began arriving in mid-1972. Shipments were resumed in 1974, and use of this material in the refinery was given priority to avoid storage.

Air samples were collected and reported in terms of the "maximum allowable concentration" (MAC). Early in the program the MAC was set at 70 dpm alpha/cubic meter. Table 2-2a lists the resulting daily weighted airborne alpha concentration in the vicinity of various worker groups and various job locations from a 1955 exposure study of Plant 1 personnel. The calculated concentrations do not include any factor for reduction of exposure through the use of respirators. Table 2-2b provides the estimated potential annual uranium intakes by Plant 1 operation personnel by the years.

Table 2-2a. Plant 1 1955 airborne radioactivity concentration by worker groups.

Groups	× MAC[a]	U Conc. α dpm/m^3	Conc. w/Respirator[b] Bq/m^3
Sample Preparation Operators	23.4	1.64E+03	5.46E-01
General Plant Operators	6.7	4.69E+02	7.82E+00
Leadman	1.4	9.80E+01	1.63E+00
Production Foreman	0.53	3.71E+01	6.18E-01
Sample Preparation Foreman	0.4	2.80E+01	4.67E-01
General Foreman	0.32	2.24E+01	3.73E-01
Superintendent	0.21	1.47E+01	2.45E-01
Storage Pad Foreman	0.16	1.12E+01	1.87E-01
Storage Pad Operator	0.15	1.05E+01	1.75E-01
Storage Pad Laborer	0.14	9.80E+00	1.63E-01
Production Records Clerks	0.11	7.70E+00	1.28E-01
Administrative Clerk	0.07	4.90E+00	8.17E-02

[a] Maximum Allowable Concentration (MAC)- 70 α dpm/m^3

[b] A Decontamination Factor (DF) of 50 for wearing respirator was applied to Breathing Zone (BZ) concentrations for selected process activities.

Table 2-2b. Projected annual uranium intake estimates by Plant 1 worker groups.

Groups	Annual Uranium Intakes Bq/yr[b]					
	1953-1954 0.6[a]	1955-1964 1.0[a]	1965-1970 0.7[a]	1971-1975 0.6[a]	1976-1981 0.25[a]	1982-1984 0.74[a]
Sample Preparation Operators	7.86E+02	1.31E+03	9.17E+02	7.86E+02	3.28E+02	9.70E+02
General Plant Operators	1.13E+04	1.88E+04	1.31E+04	1.13E+04	4.69E+03	1.39E+04
Leadman	2.35E+03	3.92E+03	2.74E+03	2.35E+03	9.80E+02	2.90E+03

Groups	Annual Uranium Intakes Bq/yr [b]					
	1953-1954 0.6[a]	1955-1964 1.0 [a]	1965-1970 0.7 [a]	1971-1975 0.6 [a]	1976-1981 0.25 [a]	1982-1984 0.74 [a]
Production Foreman	8.90E+02	1.48E+03	1.04E+03	8.90E+02	3.71E+02	1.10E+03
Sample Preparation Foreman	6.72E+02	1.12E+03	7.84E+02	6.72E+02	2.80E+02	8.29E+02
General Foreman	5.38E+02	8.96E+02	6.27E+02	5.38E+02	2.24E+02	6.63E+02
Superintendent	3.53E+02	5.88E+02	4.12E+02	3.53E+02	1.47E+02	4.35E+02
Storage Pad Foreman	2.69E+02	4.48E+02	3.14E+02	2.69E+02	1.12E+02	3.32E+02
Storage Pad Operator	2.52E+02	4.20E+02	2.94E+02	2.52E+02	1.05E+02	3.11E+02
Storage Pad Laborer	2.35E+02	3.92E+02	2.74E+02	2.35E+02	9.80E+01	2.90E+02
Production Records Clerks	1.85E+02	3.08E+02	2.16E+02	1.85E+02	7.70E+01	2.28E+02
Administrative Clerk	1.18E+02	1.96E+02	1.37E+02	1.18E+02	4.90E+01	1.45E+02

[a] Adjustment factors: The measured airborne radioactivity concentrations are adjusted for other years than the year in which the measurements are made, in accordance with the percentage of process system throughput capacity in one shift. In absence of specific throughput information, Appendix 2A is used as the default model for FEMP production rates for the derivation of the adjustment factors.

[b] Radionuclide (e.g., Pu, Np, Tc and U isotopes) radioactivity fractions for recycled uranium is given in Table 2-54.

Table 2-3a lists the maximum measured alpha air concentrations by operation or location in Plant 1. Table 2-3b provides the estimated potential annual uranium intakes by Plant 1 operation personnel by the years.

Table 2-3a. Plant 1 1955 airborne alpha concentrations by operation or location.

Operation or location	× MAC[a]	U Conc. A dpm/m^3	Conc. w/Respirator[b] Bq/m^3
Outside operation			
Deheading operation	9.0	6.30E+02	1.05E+01
Burning off battered drum lids	13.0	9.10E+02	1.52E+01
Pipe sampling operations	17.0	1.19E+03	1.98E+01
INX operations & locations			
Deheading control room	0.63	4.41E+01	7.35E-01
Drum washing station	5.78	4.05E+02	6.74E+00
2nd level	9.90	6.93E+02	1.16E+01
3rd level	5.00	3.50E+02	5.83E+00
4th level	1.70	1.19E+02	1.98E+00
Packaging control operation	33.00	2.31E+03	7.70E-01
Packaging scale operation	11.57	8.10E+02	2.70E-01
Lidding drums operation	62.5	4.38E+03	1.46E+00
Q-11 operations & location			
Hammering cake loose from drums at wash station	1.5	1.05E+02	1.75E+00
Pump area	0.46	3.22E+01	5.37E-01
Dryer area	0.40	2.80E+01	4.67E-01
Panel board area	0.31	2.17E+01	3.62E-01
2nd floor area	6.59	4.61E+02	7.69E+00
3rd floor area	1.2	8.40E+01	1.40E+00
4th floor area	4.09	2.86E+02	4.77E+00
Putting drums on conveyor for packaging	0.9	6.30E+01	1.05E+00
Packaging control operator	2.00	1.40E+02	2.33E+00
Lidding drums operation	120.00	8.40E+03	2.80E+00
Thaw tunnel control room	3.34	2.34E+02	3.90E+00
Sample preparation room			

Operation or location	× MAC[a]	U Conc. A dpm/m^3	Conc. w/Respirator[b] Bq/m^3
Spooning thorium nitrate into blender	10.3	7.21E+02	1.20E+01
Emptying Texas City ore out of blender	2.7	1.89E+02	3.15E+00
Pulverizing Texas City ore	0.54	3.78E+01	6.30E-01
Blending black oxide inside K-65 dry box	0.80	5.60E+01	9.33E-01
Blending black oxide outside (no longer done outside hood)	566.00	3.96E+04	1.32E+01
Pulverizing Q-11 inside hood	0.63	4.41E+01	7.35E-01
Cleaning Q-11 from screens outside hood on table	309.00	2.16E+04	7.21E+00
Blending Q-11 inside hood	2.00	1.40E+02	2.33E+00
Rolling Q-11 outside hood	6.00	4.20E+02	7.00E+00
Canning Q-11 outside hood	3.2	2.24E+02	3.73E+00
Putting Q-11 into screening pans outside hood	63.00	4.41E+03	1.47E+00
Riffling South African ore outside hood	96.00	6.72E+03	2.24E+00
Pulverizing African ore in DFC pulverizer inside hood	3.20	2.24E+02	3.73E+00
Cleaning African ore from DFC pulverizer inside hood	2.9	2.03E+02	3.38E+00
Blending and canning ammonium diuranate outside of hood	10.60	7.42E+02	1.24E+01
Pipe sampling ammonium diuranate outside hood	3.70	2.59E+02	4.32E+00
Grinding ammonium diuranate inside hood	2.5	1.75E+02	2.92E+00
Pipe sampling green salt outside hood	53.00	3.71E+03	1.24E+00
Blending green salt and canning under hood	126.00	8.82E+03	2.94E+00
Miscellaneous areas			
Maintenance shop	0.63	4.41E+01	7.35E-01
Washroom	1.04	7.28E+01	1.21E+00
Average over Plant 1 areas and operations	36.59	2.34E+03	4.03E+00

[a] Maximum Allowable Concentration (MAC)- 70 α dpm/m^3.
[b] A Decontamination Factor (DF) of 50 for wearing respirator was applied to Breathing Zone (BZ) concentrations for selected process activities.

2.2.3 Plant 2/3 – Refinery

The Refinery was built in 1953 and had a ground floor area of 36,604 sq. feet. The refinery converted the Government stockpile of natural uranium ore concentrates to UO_3. In 1988, the refinery operated intermittently on a sequential campaign mode to convert enriched recycled materials to oxide. The principal capabilities of the refinery were:

- Digesting enriched uranium recycled materials in nitric acid and storing blended feed solutions in stainless-steel tanks;
- Performing solvent extraction operations in stainless-steel, perforated-plate pulse columns to purify the uranium solution;

Table 2-3b. Projected annual uranium intake estimates for Plant 1 workers.

Years	Adjustment Factor[a] 1955 Data	Average Annual Uranium Intakes Bq/yr[b]
1953-1954	0.7	6.77E+03
1955-1964	1.0	9.67E+03

Years	Adjustment Factor[a] 1955 Data	Average Annual Uranium Intakes Bq/yr [b]
1965-1968	0.8	7.74E+03
1969-1971	1.0	9.67E+03
1972-1975	0.6	5.80E+03
1976-1981	0.25	2.42E+03
1982-1984	0.74	7.16E+03

[a] The measured airborne radioactivity concentrations are adjusted for other years than the year in which the measurements are made, in accordance with the percentage of process system throughput capacity in one shift. In absence of specific throughput information, Appendix 2A is used as the default model for FEMP production rates for the derivation of the adjustment factors.

[b] Radionuclide (e.g., Pu, Np, Tc and U isotopes) radioactivity fractions for recycled uranium is given in Table 2-54.

- Concentrating pure uranium solution by evaporation, and converting the uranium to UO_3;
- Recovering nitric acid from NO_x discharges from the digestion and denitration operations; and
- Recovering uranium from internal process waste solutions.

The three steps in the process of converting recycled materials to UO_3 were digestion, extraction, and denitration. Auxiliary operations included the recovery of nitric acid from nitrogen oxides and uranium from internal process liquors.

2.2.3.1 Processes and Activities

Recycle materials from various sources were conveyed into agitated tanks for digestion using nitric acid. The resulting slurry consisted of acid insolubles and a digest liquor of impure uranyl nitrate and excess nitric acid. Adjustments were made to ^{235}U and nitric acid concentrations. Following a check for proper solution concentrations, the blended feed was pumped to the extraction system. Low-grade uranium slurries, primarily from the leaching of enriched uranium slag materials, required filtration and evaporation.

In the extraction columns, two immiscible liquids entered from opposite ends and were pumped counter-current to each other in a pulsating manner through a large number of perforated plates. The combined actions of the pulsations, the counter-current flow, and the turbulence created by perforated plates caused the two liquids to become intimately mixed. In the primary extraction columns, the two liquids brought into contact were the aqueous feed slurry and an organic solvent – a mixture of tributyl phosphate and kerosene. The uranyl nitrate in the feed slurry was preferentially attracted to the organic solvent in the presence of nitric acid. Most of the nitric acid and impurities were left behind in the aqueous raffinate, which excluded uranium.

A raffinate mixer-settler was used in series with the primary extraction columns to further reduce the uranium content of the aqueous waste stream leaving the columns. Extraction raffinate was sent to the general sump for neutralization with slaked lime. Neutralized raffinate was sent to interim waste processing facilities for conversion to a dry solid for offsite burial.

Additional purification of the uranium in the extract stream was achieved by scrubbing with a small counterflow of water. The aqueous stream from the scrubbing operation was recycled to the digestion operation for use in preparing feed slurries.

Purified uranyl nitrate was recovered from the organic solvent stream by re-extraction with deionized water in perforated-plate pulse columns. In the absence of nitric acid, uranyl nitrate in the solvent was preferentially attracted to the water phase. After treatment with a sodium carbonate solution for removal of degradation products, the stripped solvent stream was reacidified and recycled to the primary extraction columns. The aqueous uranium nitrate product was sampled and analyzed to ensure conformance with strict chemical purity specifications before introduction to the denitration system. This aqueous uranyl nitrate product, at a concentration of approximately 100 g/l U, was sent to the denitration process.

In the denitration process, pure aqueous uranyl nitrate solution was concentrated by forced convective evaporation and high-pressure steam boildown to approximately 1,350 g/l U. It was calcined in batches in nominal 1,900-liter agitated denitration pots to yield UO_3, the end product of refinery operations. After milling, the uranium trioxide was packaged in hoppers, with each hopper containing approximately 4.5 metric uranium tons, or into 55-gallon drums.

Nitric acid and uranium were recovered in auxiliary operations. The nitric acid recovery system consisted of two bubble cap absorption towers operating in series at atmospheric pressure. This system operated in conjunction with the refinery to recover nitric acid from the NO_x fumes generated in the digestion and denitration areas and from other minor sources. The acid was returned to the digestion area for reuse in preparing feed slurries. The acid recovery operation reduced operating costs by saving acid, and reduced discharges to the environment.

Uranium in aqueous waste streams from the solvent treatment and cleanout operations was precipitated with magnesia and recycled to the digestion area.

In 1968, Plant 2/3 was used to process thorium as a thorium production test for a short duration. Few details are available regarding this process. Thorium nitrate crystals were produced in a denitration pot in Plant 2/3. Interviews with long-time employees indicated that this was a short-term operation; probably one pot of crystals was produced. Other records discuss the production of thorium oxide in Plant 2/3 by a process of denitration, redigestion, and drying.

2.2.3.2 Radiation Sources

The radioactive materials that were handled and processed in Plant 2/3 included:

- Enriched recycled uranium. This recycled uranium was known to contain traces of ^{237}Np, ^{238}Pu, and ^{239}Pu.
- Uranyl nitrate solution with variable concentrations. The solvent extraction product was at a concentration of 100 g/l U, and the evaporative concentrate was at 1,350 g/l U.
- Solid powder of UO_3.
- Extraction raffinate (K-65 material).

In March 1984, radiological measurements were made to characterize the radiation fields in the FEMP. The characterization showed a mixed photon and beta field with both low- and high-energy components. The low-energy beta component quickly became attenuated with distance from its source. The dose rate from the photon component was minor compared to the beta dose rate. Results of the gamma fluxes recorded at various stations applicable to Plant 2/3 from the Radiation

Field Characterization and Radiological Equipment Evaluation at the FEMP (Alvarez et al. 1984) are listed in Table 2-4:

Table 2-4. Plant 2/3 gamma fluxes.

Spectrum number	Location	Integrated gamma flux (photons/cm^2-sec)		
		30-225 keV	675-1050 keV	Ratio
358405	Beside UO_3 barrel	538	159	3.4
378401	Open UO_3 barrel	919	232	4.0
378411	Open U barrel; at 40 cm	891	218	4.1

A study of Plant 2/3 airborne alpha concentrations in late1955 indicated the daily weighted concentrations in the vicinity of the various groups and for the various jobs and locations in Table 2-5a. The calculated concentrations do not include any factor for reduction of exposure through the use of respirators. Table 2-5b provides the estimated potential annual uranium intakes by Plant 2/3 worker groups by the years.

Table 2-5a. Plant 2/3 airborne radioactivity concentrations in late 1955 by worker groups.

Groups	× MAC[a]	U Conc. α dpm/m^3	Conc.[b] w/Respirator[b] Bq/m^3
Recovery operator and helper	0.51	3.57E+01	5.95E-01
Leaderman	0.44	3.08E+01	5.13E-01
Sump operator	0.09	6.30E+00	1.05E-01
Foreman	0.53	3.71E+01	6.18E-01

[a] Maximum Allowable Concentration (MAC)—70 α dpm/m^3.
[b] A Decontamination Factor (DF) of 50 for wearing respirator was applied to Breathing Zone (BZ) concentrations for selected process activities.

Table 2-5b. Projected annual uranium intake estimates by Plant 2/3 worker groups.

Groups	Annual Uranium Intakes Bq/yr[b]					
	1953-1954 0.6[a]	1955-1964 1.0[a]	1965-1970 0.7[a]	1971-1975 0.6[a]	1976-1981 0.25[a]	1982-1984 0.74[a]
Recovery operator and helper	8.57E+02	1.43E+03	1.00E+03	8.57E+02	3.57E+02	1.06E+03
Leaderman	7.39E+02	1.23E+03	8.62E+02	7.39E+02	3.08E+02	9.12E+02
Sump operator	1.51E+02	2.52E+02	1.76E+02	1.51E+02	6.30E+01	1.86E+02
Foreman	8.90E+02	1.48E+03	1.04E+03	8.90E+02	3.71E+02	1.10E+03

[a] Adjustment factors: The measured airborne radioactivity concentrations are adjusted for other years than the year in which the measurements are made, in accordance with the percentage of process system throughput capacity in one shift. In absence of specific throughput information, Appendix 2A is used as the default model for FEMP production rates for the derivation of the adjustment factors.
[b] Radionuclide (e.g., Pu, Np, Tc and U isotopes) radioactivity fractions for recycled uranium is given in Table 2-54.

Table 2-6a lists the maximum measured alpha concentration of radioactive dust by operation or location in Plant 2/3. Table 2-6b provides the estimated potential annual uranium intakes by Plant 2/3 workers by the years.

Table 2-6a. Plant 2/3 airborne radioactivity concentration by operation or location in late 1955.

Operation or location	Ave. Conc. dpm/m^3	Conc. w/Respirator[a] Bq/m^3
Hot Raffinate		
Hot Tank Room	8	1.33E-01
Control Board, main floor	60	1.00E+00
K-65 Slurry Pump Area	70	1.17E+00
2nd level	5	8.33E-02
Oliver Filter Area	9	1.50E-01
Control Panel Area	46	7.67E-01
Raking Filter Trough	90	1.50E+00
Combined Raffinate		
Main Level, Near Calciner	16	2.67E-01
Second Level	89	1.48E+00
Third Level	15	2.50E-01
Fourth Level	6	1.00E-01
Operating Batch Conveyor	50	8.33E-01
Nitric Recovery		
Main Level	39	6.50E-01
2nd Level	21	3.50E-01
3rd Level	8	1.33E-01
4th Level	8	1.33E-01
5th Level	5	8.33E-02
6th Level	15	2.50E-01
Control Room	62	1.03E+00
Wash Room	37	6.17E-01
Ozone Room	4	6.67E-02
Maintenance Office	17	2.83E-01
General Sump Tank Area, Ground Level	4	6.67E-02
General Sump Tank Area, Second Level	6	1.00E-01
General Sump Building, First Level	7	1.17E-01
General Sump Building, Second Floor	6	1.00E-01
Average over Plant 2/3 areas and operations	24.5	3.18E-01

[a] A Decontamination Factor (DF) of 50 for wearing respirator was applied to Breathing Zone (BZ) concentrations for selected process activities.

2.2.4 Plant 4 – Green Salt Plant

In October 1953, the Green Salt Plant began to produce green salt (UF_4) from UO_3. The ground floor area was 26,500 sq. ft. The UO_3 was either produced in the refinery or recycled from other DOE sites. The primary functions of the Green Salt Plant are:

- Processing UO_3 to uranium tetrafluoride, UF_4, or green salt, in continuous-flow reactor banks designed and staged for gas-solid reactions
- Blending and packaging depleted UF_4 for the Metal Production Plant (Plant 5)
- Operating the tank farm to supply production plants with bulk quantities of required liquid chemical agents

Table 2-6b. Projected annual uranium intake estimates by Plant 2/3 workers.

Years	Adjustment Factor[a] 1955 Data	Average Annual Uranium Intakes[b] Bq/yr
1953-1954	0.7	5.34E+02
1955-1964	1.0	7.63E+02
1965-1968	0.8	6.11E+02
1969-1971	1.0	7.63E+02
1972-1975	0.6	4.58E+02
1976-1981	0.25	1.91E+02
1982-1984	0.74	5.65E+02
1985-1989	0.4	3.05E+02

[a] Adjustment factors: The measured airborne radioactivity concentrations are adjusted for other years than the year in which the measurements are made, in accordance with the percentage of process system throughput capacity in one shift. In absence of specific throughput information, Appendix 2A is used as the default model for FEMP production rates for the derivation of the adjustment factors.

[b] Radionuclide (e.g., Pu, Np, Tc and U isotopes) radioactivity fractions for recycled uranium is given in Table 2-54.

In the Green Salt Plant UO_3 was converted to uranium dioxide, UO_2, or brown oxide, by reducing it with hydrogen. The UO_2 was converted to UF_4 in a reaction with anhydrous hydrogen fluoride. The UO_3 recycled from the reactor sites underwent double pass Reduction-Oxidation-Reduction (R-O-R) processing to achieve high yields of product UF_4.

2.2.4.1 Processes and Activities

Mobile hoppers delivered the orange oxide to stainless-steel fluid bed reactors, which were heated to approximately 1,100ºF. Dissociated ammonia entered the bottom of the reactors through a gas diffuser. The hydrogen and nitrogen held the UO_3 powder in suspension. Partially converted UO_3 overflowed from the first fluid bed reactor into the second, where the reaction with hydrogen was completed.

Hydrofluorination took place in groups of three heated horizontal ribbon-screw reactors, arranged in vertical stacks. Uranium dioxide entered at one end of the top reactor, and was conveyed slowly to the other end and stirred by a power-driven ribbon screw. The operating temperature was progressively higher for each reactor, starting at approximately 300ºF at the first and ranging up to 1,200º F at the third. Anhydrous hydrogen fluoride gas entered at the discharge end of the first and third reactors and flowed countercurrent to the powder flow. The UF_4 product was weighed, blended, sampled for chemical analysis, and packaged in 38-liter cans for transportation to Plant 5.

Initial production throughput from Plant 4 did not progress as rapidly as expected. It was not until 1956, when 5,029 MTU was achieved, that the design rate of 5,193 MTU/yr was approached.

Normal and enriched UF_4 production decreased during 1967 and 1970 because of declining demand. Plant 4 operated only 4 months in 1971, and 2 months in 1972, on enriched UF_4 production. The plant was idle during 1973.

In April 1974, production began on enriched UF_4 for the New Production Reactor (NPR) Stream and continued through June. Another enriched campaign occurred from January through April 1975.

The Plant 4 process was idle from the 1975 enriched campaign through 1977. A small campaign occurred in 1978 and the plant was again shut down in 1979. In 1980, the process was restarted and operated packaging depleted UF_4 from T-hoppers into cans for the Mark 31 stream, processing UO_3 and UF_4 T-hoppers, and operating the Tank Farm.

In 1954, Plant 4 was used for a short campaign to produce dry ThF_4 from the ThO_2 dried and calcined in Plant 9 in hydrofluorination Bank 7. The ThF_4 was returned to Plant 9 and used to produce thorium metal. This was a short-duration process due to mechanical difficulties in Bank 7. Production quantities are not available for ThF_4 production in Plant 4.

2.2.4.2 Radiation Sources

The following is a chronology the history of radioactive sources in the feed materials; the primary radioactive sources are UO_3 (orange oxide), UO_2 (brown oxide), and UF_6 (green salt) powders:

1. Initially it was planned that all UO_3 feed would come from the FEMP refinery. However, in 1957, large quantities of UO_3 from the Port Hope Refinery in Canada became available for process, in addition to FEMP refinery output.

2. Recycling of low ^{236}U ("300") and high ^{236}U ("500") enriched materials began in 1960, and required complete segregation from standard UO_3 and other enriched UO_3 generation.

3. After the shutdown of the FEMP refinery in 1962, all UO_3 feed for Plant 4 came from MCW, Port Hope, Hanford, and the Savannah River Site.

4. Beginning in 1965, enriched UO_3 produced from the FEMP Slightly Enriched Recovery Facility (SERF) process was used as feed. Other UO_3 feed that year included MCW normal pot, MCW normal fluid bed, Port Hope normal and recycle UO_3 from Hanford and Savannah River Site. Receipt of these materials continued through 1971.

Table 2-7a lists the 1965 airborne radioactive material concentrations for various operations and locations at Plant 4. Table 2-7b provides the estimated potential annual uranium intakes by Plant 4 workers by the years.

Table 2-7a. Plant 4 airborne radioactivity concentrations by operation or location in 1965.

Operation or location	Ave. conc. dpm/m^3	Conc. w/Respirator[a] Bq/m^3
Level 629		
General southwest area	125.2	2.09E+00
General northwest area	103.3	1.72E+00
General northeast area	180.8	3.01E+00
General southeast area	200.3	3.34E+00
"Enriched" packaging station (no respirator worn)		
Weighing empty cans before charging with UF_4	154.3	5.14E-02
Charging cans	313.3	1.04E-01
Adjusting weight of packaged UF_4	283.3	9.44E-02
Hanford orange oxide		
Charging "T" hopper at Bank 2 east side (respirator worn)	74	2.47E-02
Charging "T" hopper at Bank 3 east side (respirator worn)	400	1.33E-01
Two operators changing mobile hopper Bank 1	175	5.83E-02
5 ft north of Bank 1 while changing hopper	86.5	2.88E-02

Operation or location	Ave. conc. dpm/m^3	Conc. w/Respirator[a] Bq/m^3
10 ft north of mobile hopper while being changed	100	3.33E-02
10 ft south of mobile hopper while being changed	160	5.33E-02
5 ft south of Bank 1 while changing hopper	185	6.17E-02
Two operators removing empty “T” hopper from Bank 3	130	4.33E-02
7 ft south of Bank 3 while changing hopper	350	1.17E-01
7 ft north of Bank 3 while changing hopper	62	2.07E-02
General level at Bank 3 slightly south	53.5	1.78E-02
On rail in front of Bank 2	205	6.83E-02
South end of east rail	14.5	2.42E-01
Removing empty T hopper from Bank 7	84	2.80E-02
Replacing full T hopper on Bank 7	280	9.33E-02
7 ft north of Bank 7	270	9.00E-02
5 ft south of Bank 7	170	5.67E-02
Removing T hopper from Bank 9 (no respirator)	510	1.70E-01
Putting full T hopper on Bank 9	77	2.57E-02
10 ft south of Bank 9	120	2.00E+00
10 ft north of Bank 9	63	1.05E+00
Two operators changing mobile hopper Bank 1	45	1.50E-02
10 ft north of Bank 1 while hopper was being changed	71	1.18E+00
10 ft south of Bank 1 while hopper was being changed	15.5	2.58E-01
East Reblend Dumping Station		
Dumping UF_4	69.57	2.32E-02
5 ft north of dumping station	62	1.03E+00
5 ft south of dumping station	25	4.17E-01
West Side Dumping Station- guillotine door open while dumping		
Operator dumping 10-gal cans of UF_4	150.3	5.01E-02
5 ft south of dumping station	67	1.12E+00
10 ft west of dumping station	10.3	1.72E-01
East Side Dumping Station		
Operator dumping 10-gal cans of UF_4	138	4.60E-02
5 ft north of dumping station	16.7	2.78E-01
10 ft south of dumping station	37.5	6.25E-01
East H_2 Burnoff		
7 ft northwest of East Burnoff	356.7	1.19E-01
15 ft west of East Burnoff	215.3	7.18E-02
7 ft southwest of East Burnoff	293.3	9.78E-02
2 ft from tempering unit East Burnoff (process)	15,775	5.26E+00
Level 619 (5th Level)		
General northeast area	137.3	2.29E+00
General northwest area	212.8	3.55E+00
General southeast area	166.7	2.78E+00
General southwest area	114.3	1.91E+00
Smoking area	83.8	1.40E+00
Maintenance area	12.9	2.15E-01
HF Recovery area	9.7	1.62E-01
Enriched material Dumping Station		
Dumping UF4 at dumping station north side	101	3.37E-02
7 ft south of dumping station	25.3	4.22E-01
7 ft north of dumping station	29.7	4.95E-01
Weighing empty cans at west charging station	35.3	5.88E-01
Dust Collector Drumming Station		0.00E+00

Operation or location	Ave. conc. dpm/m^3	Conc. w/Respirator[a] Bq/m^3
Checking and changing of drums (respirator worn)	1,090	3.63E-01
10 ft east during changing and checking of drums at drumming station	13.7	2.28E-01
10 ft west during changing and checking of drums	122.3	2.04E+00
"Enriched" UO_3 dumping station (respirator worn)		
Operator sampling reactor	1,493.3	4.98E-01
Delipping, pumping and relipping drum	669	1.12E+01
Enriched uranium packaging station		
5 ft southwest of UF_4 charging station	27.3	4.55E-01
10 ft north of UF_4 adjusting weigh station	133	2.22E+00
Level 608 (4th Level)		
General southwest area (605 level)	47.2	7.87E-01
General northwest area (605 level)	259.5	4.33E+00
General southwest area (610 level)	21.2	3.53E-01
General northwest area (610 level)	28.2	4.70E-01
HF Recovery Area	12	2.00E-01
Level 597 (3rd Level)		
General southeast area	13.7	2.28E-01
General northeast area	22	3.67E-01
General northwest area	15.3	2.55E-01
General southwest area	14.3	2.38E-01
Smoking area	24.3	4.05E-01
HF Recovery area	8.7	1.45E-01
Operator sampling reactor 1	22	7.33E-03
Operator sampling reactor 2	82	2.73E-02
Operator sampling reactor 7	100	3.33E-02
Operator sampling reactor 8	110	3.67E-02
Operator sampling reactor 9	13	4.33E-03
Level 588 (Mezzanine)		
General southwest area	63	1.05E+00
General northwest area	32	5.33E-01
General southeast area	15.7	2.62E-01
General north east area	16	2.67E-01
HF Recovery Area	10.7	1.78E-01
Level 580		
General west side near water fountain area	60	1.00E+00
General north side near door area	127	2.12E+00
General east side near packaging station	49	8.17E-01
General south side near scale area	12.7	2.12E-01
East Packaging Station (enriched material)		
Weighing empty can before charging with UF_4	18	3.00E-01
Charging cans of UF_4	42.3	1.41E-02
Adjusting weigh of package UF_4 and wiping can	4.3	7.17E-02
8 ft south of UF_4 canning station	5.0	8.33E-02
10 ft southwest of UF_4 canning station	4.7	7.83E-02
West Canning Station		
Weighing empty can before charging with UF_4	103.7	3.46E-02
Charging cans of UF_4	23	7.67E-03
Adjusting weigh of package UF_4 and wiping can	12.3	4.10E-03
8 ft north of UF_4 packaging station	27.3	4.55E-01
10 ft northeast of UF_4 packaging station	32.3	5.38E-01

Operation or location	Ave. conc. dpm/m^3	Conc. w/Respirator[a] Bq/m^3
Enriched uranium packaging station		
10 ft north of UF_4 adjusting weigh station	75.7	1.26E+00
5 ft southwest of UF_4 charging station	42.3	7.05E-01
Charging cans	36	1.20E-02
Adjusting weight of packaged UF_4	103.3	3.44E-02
Weighing empty cans before charging with UF_4	56.7	1.89E-02
Blender operations		
Operator collecting and changing sample bottles at 3 blender-enriched	48.5	1.62E-02
Operator collecting and changing sample bottles at 2 blender	133	4.43E-02
First Level		
Ammonia Disassociator Area	21	3.50E-01
Administrative and offices	14.7	2.45E-01
HF Recovery Area	11.7	1.95E-01
Sump pump	2.7	4.50E-02
West pad	12	2.00E-01
East pad	6.0	1.00E-01
Average over Plant 4 areas and operations	261.5	6.80E-01

[a] A Decontamination Factor (DF) of 50 for wearing respirator was applied to Breathing Zone (BZ) concentrations for selected process activities.

2.2.5 Plant 5 – Metals Production Plant

Construction of this facility was complete in 1953. The ground floor area was 58,620 ft^2. At the Metal Production Plant, UF_4, the product of Plant 4 and the Pilot Plant, underwent a thermite-type reaction with magnesium to produce uranium metal. The principal functions of the Metals Production Plant were:

- Reducing uranium tetrafluoride to high-purity depleted, normal, and enriched uranium derby metal with magnesium in electric resistance furnaces.
- Casting depleted uranium derbies and recycle metal scrap into ingots using vacuum melt induction furnaces.
- Sawing ingots to size.
- Sampling metal products for quality.
- Machining graphite into almost any shape using lathes, saws, milling machines, routers, and grinders
- Milling MgF_2 slag byproduct for reuse in lining reduction pots

Table 2-7b. Projected annual uranium intake estimates by Plant 4 workers.

Years	Adjustment Factor[a] 1965 Data	Average Annual Uranium Intakes Bq/yr[f]
1953-1954	0.8	1.31E+03
1955-1964	1.1	1.80E+03
1965-1968	1.0	1.63E+03
1969-1970	1.1	1.80E+03
1971	1.0	5.44E+02[b]
1972	1.0	2.72E+02[c]
1973	0.0	0.0[d]
1974	1.0	2.72E+02[c]
1975	1.0	5.44E+02[b]
1976-1977	0.0	0.0[d]
1978	1.0	2.72E+02[e]
1979	0.0	0.0[d]
1980-1988	0.82	1.34E+03

[a] Adjustment factors: The measured airborne radioactivity concentrations are adjusted for other years than the year in which the measurements are made, in accordance with the percentage of process system throughput capacity in one shift. In absence of specific throughput information, Appendix 2A is used as the default model for FEMP production rates for the derivation of the adjustment factors.

[B] Plant 4 operated 4 months in 1971 and 1975.

[c] Plant 4 operated 2 months in 1972 and 1974.

[d] Plant 4 idled in 1973, 1976 through 1977 and 1979.

[e] Plant 4 processed a small campaign in 1978.

[f] Radionuclide (e.g., Pu, Np, Tc and U isotopes) radioactivity fractions for recycled uranium is given in Table 2-54.

2.2.5.1 Processes and Activities

To begin the reduction process that produces uranium metal, UF_4 and magnesium granules, totaling about 500 pounds, were blended and charged into a steel pot lined with magnesium fluoride slag. The pot was capped with slag to protect it from the intense heat of the reaction. Materials handling systems were included in the Productivity Retention Program to reduce worker contact with uranium materials in this area. The pot was fitted with a steel cover and heated in a resistance furnace to a temperature range of 1200° to 1500ºF for 3 to 4 hours, until the contents reacted spontaneously. At this point, the internal temperature of the pot might have reached 3,000ºF. Approximately 5 minutes after the reaction occurred, the pot was removed from the furnace and stored in an air-cooling tank for at least 1 hour, and then transferred to a water-cooling tank for several hours. After cooling, the contents were removed and the uranium mass, called a derby, was separated and cleaned by slag chipping hammers.

Standard depleted production derbies weighed approximately 167 kg U. Enriched derbies weighed approximately 152 kg U. Most of the derbies were transferred to the Metals Production Plant casting area, some were sent to the Special Products Plant casting area, and others were sent to other DOE sites. The MgF_2 slag resulting from the thermite reaction was milled for reuse as liner material.

In the casting process, cleaned depleted or normal derbies together with recycle metal scrap were charged into a graphite crucible. The loaded crucible was placed in a vacuum induction furnace and heated for about 95 minutes at 130 Kw input to approximately 2,700ºF, at which temperature it is ready to pour. A shear plug in the bottom of the crucible was broken to permit the molten metal to

flow into a heated graphite mold directly under the crucible. After cooling, the mold was separated from the ingot, cleaned, and prepared for reuse. Crucibles were flame-treated to oxidize residual uranium. On occasion, metal spills occurred from mold breakage. All product ingots cast in the Metals Production Plant were for supplying target element core requirements for reactors at the Savannah River Site. Slab billets were cast from derby metal for the Rocky Flats Plant.

As-cast ingots were cropped by sawing approximately 2 inches from the top section to remove shrinkage cavities and impurities that rose to the top of the melt after pouring and during solidification. Ingot dimensions ranged from 23 to 40 inches in length. Longer ingots were sawed in half, producing two billets for the extrusion step. After sampling, cropped ingots were transferred to the Special Products Plant for center drilling and surface machining. Before machining, as-cast ingots weighed up to 653 kg U. Machined billets weighed as much as 520 kg, and were heat-treated in Plant 6, the Metals Fabrication Plant, before being moved to another site.

2.2.5.2 Radiation Sources

Radioactive sources in Plant 5 consisted of "uranium" and "recycle uranium" of UF_4 granules, uranium metal derbies, billets, and ingots, and uranium oxide in MgF_2.

Results of gamma fluxes recorded at various stations applicable to Plant 5 from the radiation field characterization and radiological equipment evaluation efforts conducted at the FEMP are listed in Table 2-8.

Table 2-8. Plant 5 gamma fluxes.

Spectrum number	Location	Integrated gamma flux (photons/cm^2 sec)		
		30-225 keV	675-1050 keV	Ratio
358402	Graphite crucible (3898) at 30 cm	310	18	17.2
378411	Graphite crucible (G-8010)) at 30 cm	183	11	16.6
368407	Crucible Load Station (Scrap Can)	962	261	3.6
368408	Crucible Load Station (crucible)	453	76	5.9
368409	Crucible Load Station (can of briquettes)	638	163	3.9
368411	Crucible Load Station (55 gal. Drum)	990	348	2.8
368413	Crucible Burn Out Station	776	69	11.2
368414	NE Saw (Machined U ingot at 0.5 cm)	1032	358	3.6
368416	NE Saw (Black U ingot at 0.5 cm)	1130	290	3.9
378427	Box of black crop tops at 25 cm	848	154	5.5
378424	Black U ingot at 1 cm Outdoors	989	163	6.1
378417	Background just outside Building 3045	35	5	7.0
378418	Near old thorium hopper	424	58	7.3
378420	Background 75 ft. from Building 3045	25	2	12.5

An exposure study of Plant 5 production personnel to airborne radioactive dust provided the data listed in Table 2-9a. Table 2-9b provides the estimated potential annual uranium intakes by Plant 5 workers by the years.

Table 2-9a. Plant 5 airborne radioactivity concentration by operation or location (year data taken as indicated).

Operation or location	Ave. Conc. α dpm/m^3	Conc. w/Respirator[a] Bq/m^3
Plant 5 –A Area(1965 data)		
1st floor administrative and office areas	10	1.67E-01
Furnace pot cooling tank area east side	6	1.00E-01
Rockwell area east of Rockwell 16	9.3	1.55E-01
Rockwell area west of Rockwell 29	27	4.50E-01
Approximately 7 ft. west of 35 Rockwell area (GA)	43.3	7.22E-01
Furnace pot lipping area 5 ft west of pots	45	7.50E-01
Furnace pot lipping area 5 ft east of pots	18.3	3.05E-01
Furnace pot cooling tank area west side	15.3	2.55E-01
West side smoking area	23	3.83E-01
Dumping UF_4 and magnesium into No. 4 blender	74	2.47E-02
3rd floor storage area while dumping magnesium	8.77	1.46E-01
Jolters Area		
Jolter operator breathing zone	163.3	5.44E-02
General area	103.7	1.73E+00
East jolters A, B, C (General Area)	257	4.28E+00
East jolters D, F (General Area)	23.3	3.88E-01
East jolters A, B, C (Breathing zone)	52.6	1.75E-02
West jolters (General Area)	93	1.55E+00
West jolters between J and K (GA)	17.7	2.95E-01
West jolters (BZ)	45.7	7.62E-01
East side of jolters D, E, F (GA)	87.2	1.45E+00
East side of jolters D, E, F (BZ)	191	6.37E-02
West side of jolters H, I, J, K (GA)	112.3	1.87E+00
West side of jolters H, I, J, K (BZ)	260	8.67E-02
Removing pot from jolter	716.7	2.39E-01
Dumping bad MgF_2 liner west side north of jolters	316	1.05E-01
7 ft south of dumping station during dumping of broken liner	183.3	6.11E-02
7 ft north of dumping station during dumping of broken liner	273.3	9.11E-02
Pot charging		
GA during pot charging at bottom F machine	102	1.70E+00
BZ during pot charging at bottom F machine 4	44.8	1.49E-02
Operator placing MgF_2 liner into pot with scoop; taming with scoop; scraping pot with back of saw blade; vacuuming and removing pots (Breathing Zone) (1969 data)	91.5	3.05E-02
Capping Stations		
BZ Capping pots at No. 3 station	32	1.07E-02
GA Capping pots at No. 3 station	10.8	1.80E-01
Capping pots at No. 1 station	65.7	2.19E-02
No. 1 capping station	33.5	5.58E-01
East Breakout Area		
Smoking area	41.3	6.88E-01
Breakout platform	56.7	9.45E-01
Breakout operation at the platform (BZ)	89.25	2.98E-02
Delipping furnace pots and breaking crust	301.2	1.00E-01
Breakout area desk	40.3	6.72E-01
Cleaning derbies and breaking slag	280.9	9.36E-02
Weighing and marking derbies	68	2.27E-02

Operation or location	Ave. Conc. α dpm/m^3	Conc. w/Respirator[a] Bq/m^3
West Breakout station		
Delidding furnace pots and breaking crust	346.7	1.16E-01
GA at breakout platform	47	7.83E-01
BZ- Breakout operation on the platform	67.3	2.24E-02
Cleaning derbies and breaking slag	30	1.00E-02
Weighing and marking derbies	17.3	5.77E-03
Breakout area	30.3	5.05E-01
Breakout smoking area	5	8.33E-02
Changing drums and lipping at the west slag drumming station	39	1.30E-02
5 ft southeast of drumming station	12.7	2.12E-01
Stenciling empty drums at drumming station (BZ)	35.7	1.19E-02
Stenciling empty drums at drumming station (GA)	153.7	2.56E+00
Hoffman Canning Station		
Checking Hoffmans and shaking bags	2,033.3	6.78E-01
Changing drums	4,983	1.66E+00
Emptying collectors	638.4	2.13E-01
5 ft north of Hoffman 248, 253, 241	131	4.37E-02
5 ft south of Hoffman 248, 253, 247	32.8	1.09E-02
3 ft south of Hoffman canning station 261	1,280	4.27E-01
3 ft north of Hoffman canning station 261	1,787	5.96E-01
Residue Area		
Weighing and marking drums of residue at scale	30	5.00E-01
During operation at the residue scale	22	3.67E-01
Plant 5 B Area		
Administrative and office areas	19.8	3.30E-01
Graphite shop	5.3	8.83E-02
East remelt furnaces area north end	71.3	1.19E+00
East remelt furnaces area south end	61	1.02E+00
West furnace area north end	31	5.17E-01
West furnace area south end	53	8.83E-01
Midway between east and west charge station	72.7	1.21E+00
Scrap storage area 2nd floor north end	43.7	7.28E-01
Ingot storage area 1st floor north	56	9.33E-01
Ingot storage area smoking area	60.3	1.01E+00
Shipping area 1st floor north	51	8.50E-01
Charging Station		
Station desk at east charging station	117.3	1.96E+00
Operator charging material at east charging station	150	5.00E-02
Station desk at west charging station	58.3	9.72E-01
Operator charging material at west charging station	46.8	1.56E-02
Lathe Area		
Putting cut in lathe cutting cup and removing cup from lathe	72.5	2.42E-02
4 ft north of lathe during operation	31	5.17E-01
Operator putting contaminated mold in lathe	178	5.93E-02
Working controls and operating contaminated lathe	75	2.50E-02
Removing contaminated mold from lathe	51.3	1.71E-02
4 ft southwest of lathe	16.7	2.78E-01
East Bottom Remelt Furnaces		
Removing cup and uncovering furnace, placing cup and mold inside furnace	10.6	3.56E-03
Lowering mold tank from furnace, and transporting to cooling tunnel	396.8	1.32E-01

Operation or location	Ave. Conc. α dpm/m^3	Conc. w/Respirator[a] Bq/m^3
Raising and lowering ram inside of buggy	101.3	3.38E-02
Raising and lowering ram without use of buggy	331	1.10E-01
Placing mold in open furnace	127	4.23E-02
Attaching mold tank to bottom furnace	386.3	1.29E-01
East furnace area	38	6.33E-01
Smoking area	69.3	1.16E+00
North of furnace 14	123.3	2.06E+00
West Bottom Remelt Furnaces		
Removing cup and vacuuming furnace	1,392.5	4.64E-01
Placing mold in mold tank	435	1.45E-01
West furnace area	35.7	5.95E-01
Lowering mold tank from furnace, and transporting to cooling tunnel	121.3	4.04E-02
Raising and lowering ram inside buggy	123	4.10E-02
Placing mold in open furnace	196.7	6.56E-02
Smoking area	42	7.00E-01
North of 28 furnace north end	220	3.67E+00
South of 15 furnace north end	41.3	6.88E-01
Separation Booths		
Vacuuming top of ingot and separating ingot and mold at west booth	43.7	1.46E-02
West separation booth general area	46.7	7.78E-01
Vacuuming top of ingot and separating ingot and mold at east booth	74.7	2.49E-02
East separation booth general area	38.8	6.47E-01
East Saw Area		
East saw general area	68.3	1.14E+00
During operation of east circular saw	32	5.33E-01
Operating east circular saw	58	1.93E-02
Setting up ingot	813.3	2.71E-01
Removing ingot from saw weighing and stamping	480	1.60E-01
Removing sample from saw and stamping	693.3	2.31E-01
Cropping 10-in depleted ingots(1976 data)		
Millipore filter sampling (BZ)	27.6	4.60E-01
East Saw operator's desk (GA)	59.3	9.88E-01
Column southwest of saw	225	3.75E+00
Electric box northwest of saw	16	2.67E-01
10 ft south of saw blade at conveyor	77	1.28E+00
Mold reconditioning area	56.7	9.45E-01
Cleaning and coating molds inside enclosure	55.7	9.28E-01
Coating cups	101	1.68E+00
West Saw Area		
West saw general area	57	9.50E-01
During operation of east circular saw	32	5.33E-01
Operating east circular saw	58	9.67E-01
Setting up ingot	235.3	7.84E-02
Removing ingot from saw weighing and stamping	292	9.73E-02
Removing sample from saw and stamping	354.3	1.18E-01
North Saw Area		
Operating saw sharpener	36.3	6.05E-01
Saw sharpening area	12.7	2.12E-01
Operating north circular saw (BZ)	54.8	9.13E-01
During saw operation	12.7	2.12E-01

Operation or location	Ave. Conc. α dpm/m^3	Conc. w/Respirator[a] Bq/m^3
Crucible Assembling Area		
Knocking out plug, putting new plug in crucible and painting inside of crucible	110.3	3.68E-02
5 ft south of crucible assembling station	143	4.77E-02
5 ft north of crucible assembling station	154.5	5.15E-02
Working controls at west burnout station 2nd floor	67	1.12E+00
Working controls at east burnout station 2nd floor	44	7.33E-01
Graphite crusher		
Breaking and charging graphite to crusher 2nd floor	823.3	2.74E-01
GA during charging crusher operation	1,533	5.11E-01
Changing and weighing drums at drumming station 1st floor	3,233	1.08E+00
7 ft northwest of crusher while charging	147.8	4.93E-02
East Burnout Canning Station		
Changing drum and lipping	613.3	2.04E-01
Cleaning dirty pot lips at east pot lip cleaning station	33.8	1.13E-02
Filter Press		
5 ft north of press	19.3	6.43E-03
5 ft south of press	529.4	1.76E-01
Operator cleaning filter press	216	7.20E-02

[a] A Decontamination Factor (DF) of 50 for wearing respirator was applied to Breathing Zone (BZ) concentrations for selected process activities.

Table 2-9b. Projected annual uranium intake estimates by Plant 5 workers.

Years	Adjustment Factor[a]		Average Uranium Conc. Bq/m^3	Average Annual Uranium Intakes Bq/yr[b]
	1965 Data	1976 Data		
1953-1954	0.5	2.0	4.09E-01	9.82E+02
1955-1964	1.1	4.1	8.65E-01	2.08E+03
1965-1968	1.0	3.7	7.83E-01	1.88E+03
1969-1971	1.1	4.1	8.65E-01	2.08E+03
1972-1975	0.67	2.4	6.64E-01	1.59E+03
1976-1981	0.15	1.0	1.67E-01	4.02E+02
1982-1984	0.28	3.0	4.42E-01	1.06E+03
1985-1989	0.82	1.0	4.03E-01	9.68E+02

[a] Adjustment factors: The measured airborne radioactivity concentrations are adjusted for other years than the year in which the measurements are made, in accordance with the percentage of process system throughput capacity in one shift. In absence of specific throughput information, Appendix 2A is used as the default model for FEMP production rates for the derivation of the adjustment factors.

[b] Radionuclide (e.g., Pu, Np, Tc and U isotopes) radioactivity fractions for recycled uranium is given in Table 2-54.

2.2.6 Plant 6 – Metals Fabrication Plant

The ground floor area of the Metals Fabrication Plant was 206,270 sq. ft. At this plant, uranium metal products were heat-treated to improve their strength and grain structure. Some of these products were shipped off the site for extrusion. The extruded tubes were returned to the Metals Fabrication Plant to be machined into final products. After being inspected to ensure the highest quality, the products were shipped to other DOE sites. The principal capabilities of the Metals Fabrication Plant were:

- Heat treating machined ingots for extrusion using neutral salt (NuSal) furnace and salt-oil baths.
- Heat-treating and final machining of target elements or fuel cores.
- Cropping, surface milling, and inspecting products for shipment.
- Metal pickling and chip briquetting.
- Providing standby capabilities for rolling as-cast ingots into rods that had close dimensional tolerances.
- Inspecting finished target element cores and final products before shipment.

2.2.6.1 Processes and Activities

All center drilled and machined ingots and billets received from the Special Products Plant were heat-treated in a molten salt bath (50% NaCl, 50% KCl) at 1,350º F and water-quenched to achieve the beta phase grain structure for improving extrusion and final machining yields. Heat-treated ingots and billets were extruded into tubular forms having various inside and outside diameter dimensions. Extruded billets for N-Reactor were fabricated at Hanford, while extruded tubes produced for the Savannah River Site were returned to the FEMP for target element core fabrication.

Extruded tubes were cut into 8-inch lengths using a cut-off lathe. After salt heating in the beta range and oil quenching, final machining was performed automatically on the Cross Transformatic machine. The machined elements were individually stamped for identification and processed through a degreasing step. Machining chips were recrushed, pickled, rinsed, dried, briquetted, and recycled to casting operations. NO_x destruction equipment was installed on the pickling system exhaust. Cleaned finished pieces were conveyed to the Final Inspection Area for testing by instrumental nondestructive techniques.

Depleted uranium nonbriquettable turnings were oxidized in a Recovery Plant furnace; nonremeltable metal spills and secondary top crops were stored on an outdoor concrete pad for potential sale to the commercial nuclear industry. Enriched uranium nonbriquettable turnings were sent to the Recovery Plant for oxidation; the nonremeltable metal spills and top crops are recovered by dissolution in a refinery metal dissolver tank, using nitric acid.

The standby rolling mill facility consisted of an ingot preheat furnace, blooming mill, crop shear, equalizing furnace, flying shear and related conveying, and cooling and rod straightening equipment. The rolling capacity for oval billets and round rod was approximately 36 metric tons/day based on one-shift operation.

2.2.6.2 Radiation Sources

Radioactive sources included uranium and recycle uranium metal.

Results of the gamma fluxes recorded at various stations applicable to Plant 6 from the radiation field characterization and radiological equipment evaluation at the FEMP are listed in Table 2-10.

Table 2-10. Plant 6 gamma fluxes.

Spectrum number	Location	Integrated gamma flux (photons/cm sec)		
		30-225 keV	675-1050 keV	Ratio
388403	Tube cutting work station	253	58	4.4
388406	Tube packing work station	155	34	4.6
388407	Box of packed tubes at 1 cm	1,273	348	3.7

The results of airborne radioactivity surveillance data for Plant 6 are listed in Table 2-11a. Table 2-11b provides the estimated potential annual uranium intakes by Plant 6 workers by the years.

Table 2-11a. Plant 6 airborne radioactivity concentration by operation or location.(year data taken as indicated)

Operation or Location	Ave. Conc. α dpm/m^3	Conc. w/Respirator[a] Bq/m^3
Beta slug furnace and rolling mill (1959 data) Sample results obtained before modification of furnace		
Taken 2 ft from furnace	99	1.65E+00
Taken 4 ft from furnace	276	4.60E+00
Rod stamping area about 25 ft south of furnace	375	6.25E+00
Aisle 15 ft west of furnace.	158	2.63E+00
Sample results obtained after modification of furnace		
Taken 2 ft from west side of furnace	50	8.33E-01
South end of furnace, ≈ 18 in. from salt bath.	13	2.17E-01
North end of furnace, ≈ 18 in. from salt bath.	33	5.50E-01
Rod stamping area about 25 ft south of furnace	8	1.33E-01
Top of electrical bay, 4 ft east of cooling bed	24	4.00E-01
West side of furnace	38	6.33E-01
Slug loading and unloading area	27	4.50E-01
East side of furnace where operator works crane	30	5.00E-01
Air dust evaluation of NuSal Treatment (1958 data)		
Pump hanging on crane hooks 3-4 ft directly above furnace, slugs in furnace	56	9.33E-01
Adding slugs to furnace	276	4.60E+00
Pump 12 ft west of furnace. Slugs being treated. Visible smoke. Cause eye burning	297	4.95E+00
Pump in smoking area situated 15-20 ft east of furnace. Slugs being treated.	104	1.73E+00
Pump 15 ft east of crop shear pulpit in aisle at face level. Slugs being treated	87	1.45E+00
Pump 15 ft east of blooming mill pulpit in aisle at face level. Slugs being treated	60	1.00E+00
Air dust evaluation of turret lathes (1956 data)		
No. 1 turret lathe operator	43	7.17E-01
No. 2 turret lathe operator	150	2.50E+00
No. 3 turret lathe operator	417	6.95E+00
No. 4 turret lathe operator	199	3.32E+00
Lathe area	313	5.22E+00

[a] A Decontamination Factor (DF) of 50 for wearing respirator was applied to Breathing Zone (BZ) concentrations for selected process activities.

Table 2-11b. Projected annual estimated uranium intake by Plant 6 workers.

Years	Adjustment Factor[a] 1956, 1958,1959 Data	Average Uranium Conc. Bq/m^3	Average Annual Uranium Intakes[b] Bq/yr
1953-1954	0.5	1.01E+00	2.41E+03
1955-1964	1.0	2.01E+00	4.82E+03
1965-1968	0.9	1.81E+00	4.34E+03
1969-1971	0.6	1.21E+00	2.89E+03
1972-1975	0.6	1.21E+00	2.89E+03
1976-1981	0.25	5.03E-01	1.21E+03
1982-1984	0.74	1.49E+00	3.57E+03
1985-1988	0.2	4.02E-01	9.65E+02

[a] The measured airborne radioactivity concentrations are adjusted for other years than the year in which the measurements are made, in accordance with the percentage of process system throughput capacity in one shift. In absence of specific throughput information, Appendix 2A is used as the default model for FEMP production rates for the derivation of the adjustment factors.

[b] Radionuclide (e.g., Pu, Np, Tc and U isotopes) radioactivity fractions for recycled uranium is given in Table 2-54.

2.2.7 Plant 7 – Hexafluoride Reduction Plant

Plant 7 operations began in June 1954. The plant converted uranium hexafluoride to green salt using the same process as the Pilot Plant. The green salt was used in Plant 5 to produce uranium metal. After only 2 years of operation, the U.S. Atomic Energy Commission (AEC) directed the shutdown of Plant 7 because a similar processing plant was operating in Paducah, Kentucky. For the next 13 years, site management considered several proposals for the idle facility, but none were accepted. In 1969, all equipment was excessed and sold, and the building was used to store drums of green salt and empty containers.

2.2.7.1 Processes and Activities

Plant 7 was designed for the conversion of UF_6 to UF_4 in a gas-gas reaction. UF_6 gas vaporized from storage cylinders was mixed with hydrogen gas produced by ammonia dissociation in a specially designed nozzle inside a tapered vertical reaction tower maintained at approximately 100°F with 100 kW heaters and forced-air cooling.

Most of the solid UF_4 formed in the reaction settled downward in the tower as a fine powder, and was collected in a surge hopper. Some of the product was carried out of the reactor with byproduct HF and excess hydrogen and collected. The product UF_4 was conveyed through a micropulverizer, batch-blended, packaged into 10-gallon cans, and weighed.

The filtered gases, HF, H_2, and N_2, leaving the solid collection system were passed through a Monel wool filter, cooled to 150°F, passed through a CaF_2 chemical trap, and refrigerated to minus 90°F. The condensed anhydrous liquid HF was sent to the Tank Farm for in-plant storage prior to use or sale. The uncondensed HF was absorbed and neutralized in a lime slurry system. Hydrogen leaving the scrubbers was burned and the combustion gases vented to the atmosphere.

The design capacity of this plant was 12 tons per day of uranium as uranium tetrafluoride, split evenly between depleted and normal uranium from two sets of four reactors each. One on-stream spare reactor per set was included.

At the completion of plant construction, the capability was determined to be a UF_6 feed rate of 300 pounds per hour. Based on a 75% on-stream factor for the eight-reactor capacity, the UF_4 production rate was calculated at 14.6 tons per day. By December 1955, the UF_6 feed rate was at 550 pounds per hour and the UF_4 rate was at 26.76 tons per day.

2.2.7.2 Radiation Sources

The sources of radioactivity during the limited years of operation for Plant 7 were UF_6 and UF_4.

An exposure study of Plant 7 production personnel to airborne radioactive dust provided the data listed in Table 2-12. The last two columns of Table 2-12 provide the estimated potential annual uranium intakes by Plant 7 worker groups by the years.

Table 2-12. Plant 7 airborne radioactivity concentration and uranium intakes by worker groups.

	Ave. 1955 and 1956 Data			Annual Uranium Intakes [d] Bq/yr	
Job description	× MAC[a]	Conc. α dpm/m^3	Conc. Bq/m^3	1954[b]	1955-1956[c]
Packaging helpers	1.56	109.2	1.82E+00	2.18E+03	4.37E+03
Packing laborers	2.20	154	2.57E+00	3.08E+03	6.16E+03
Transfer operators	3.56	248.85	4.15E+00	4.98E+03	9.95E+03
Packaging operators	0.69	48.3	8.05E-01	9.66E+02	1.93E+03
General foreman	0.45	31.15	5.19E-01	6.23E+02	1.25E+03
Reactor operators & helpers	0.36	25.2	4.20E-01	5.04E+02	1.01E+03
Vaporizer operators	0.23	15.75	2.63E-01	3.15E+02	6.30E+02
Laborers, general	0.31	21.7	3.62E-01	4.34E+02	8.68E+02
Shift foreman & lead man	0.26	18.2	3.03E-01	3.64E+02	7.28E+02
Forklift operators	0.26	18.2	3.03E-01	3.64E+02	7.28E+02
Control room operators	0.19	13.3	2.22E-01	2.66E+02	5.32E+02
Utility helpers	0.24	16.8	2.80E-01	3.36E+02	6.72E+02
Area foreman	0.19	13.3	2.22E-01	2.66E+02	5.32E+02
Superintendent	0.17	11.9	1.98E-01	2.38E+02	4.76E+02
Lime slurry operators	0.18	12.25	2.04E-01	2.45E+02	4.90E+02
Office personnel	0.10	6.65	1.11E-01	1.33E+02	2.66E+02
Chemists	0.09	109.2	1.82E+00	2.18E+03	4.37E+03

[a] Maximum Allowable Concentration (MAC) - 70 α dpm/m^3.
[b] Plant 7 operated 6 months in 1954.
[c] Maximum capacity assumed for these years.
[d] Radionuclide (e.g., Pu, Np, Tc and U isotopes) radioactivity fractions for recycled uranium is given in Table 2-54.

The results of airborne radioactive dust surveillance data for Plant 7 by operation or location are listed in Table 2-13a. Table 2-13b provides the estimated potential annual uranium intakes by Plant 7 worker by the years.

Table 2-13a. Plant 7 airborne radioactivity concentration by operation or location.

Operation or location	Type of sample	Ave.1955-1956 Data		
		× MAC[a]	Conc. α dpm/m^3	Conc. Bq/m^3
Emptying dust collectors	Breathing zone	25.55	1.79E+03	2.98E+01
Adjusting weights and lidding	Breathing zone	3.05	2.14E+02	3.56E+00
Cleaning cans after packaging	Breathing zone	3.90	2.73E+02	4.55E+00
Packaging green salt	Breathing zone	1.15	8.05E+01	1.34E+00
Changing cylinders of UF_6	General air	0.70	4.90E+01	8.17E-01
First-floor area	General air	0.54	3.75E+01	6.24E-01
Lime slurry area, 1st floor	General air	0.29	2.00E+01	3.33E-01
Smoking area, 1st floor	General air	0.39	2.73E+01	4.55E-01
Second-floor area	General air	0.09	5.95E+00	9.92E-02
Washroom, 2nd floor	General air	0.09	6.30E+00	1.05E-01
Lime slurry area, 2nd floor	General air	0.09	6.30E+00	1.05E-01
Third-floor area	General air	0.41	2.87E+01	4.78E-01
Fourth-floor area	General air	0.23	1.61E+01	2.68E-01
Fifth-floor area	General air	0.29	2.00E+01	3.33E-01
Smoking area, 5th floor	General air	0.14	9.80E+00	1.63E-01
Washroom, 5th floor	General air	0.13	9.10E+00	1.52E-01
Sixth-floor area	General air	0.27	1.86E+01	3.09E-01
Seventh floor area	General air	0.75	5.25E+01	8.75E-01
Vaporizer area	General air	0.21	1.44E+01	2.39E-01
Control room	General air	0.20	1.40E+01	2.33E-01
Area foreman's office	General air	0.07	4.55E+00	7.58E-02
Superintendent's office	General air	0.08	5.25E+00	8.75E-02
Laboratory	General air	0.08	5.60E+00	9.33E-02
STORAGE WAREHOUSE	General air	0.46	3.22E+01	5.37E-01
Storage tank area	General air	0.04	2.80E+00	4.67E-02
Average over Plant 7 areas and operations		1.6	1.1E+02	1.8E+00

[a] Maximum Allowable Concentration (MAC) - 70 α d/m per meter^3.

Table 2-13b. Projected annual estimated uranium intake by Plant 7 workers.

Years	Adjustment Factor[a] 1955-1956 Data	Average Annual Uranium Intakes Bq/yr
1954	1.0	2.16E+03[b]
1955-1956	1.0	4.32E+03

[a] Maximum capacity assumed for these years.
[b] Plant 7 operated 6 months in 1954.

2.2.8 Plant 8 – Scrap Recovery Plant

Plant 8 construction was complete in 1953 and production began in November of that year. The ground floor area was 25,500 sq. ft. In the Scrap Recovery Plant, recycled residues and scrap from uranium processing were upgraded before being sent to the refinery for uranium extraction. In addition to recycle functions, the plant equipment was used to treat enriched uranium residues. The primary functions in the Scrap Recovery Plant included:

- Furnacing various enriched residues from onsite generation and offsite receipt to prepare refinery feed by removing moisture, oil, graphite and metallic impurities;

- Filtering large volumes of low-level radioactive waste slurries using rotary vacuum precoat filters;

- Drying and heating in a furnace waste materials for offsite disposal, including contaminated filter cakes from neutralized process waste streams and Refinery slag leach operations; and

- Drum washing operations.

2.2.8.1 Processes and Activities

The Scrap Recovery Plant process primarily involved upgrading enriched uranium recycle materials from FEMP and offsite operations to produce feed materials for head-end processing in the refinery. Recycle materials containing metallic uranium or magnesium, oil, graphite, or other troublesome agents were roasted to oxidize the components. Oversize pieces were screened and milled. Wet materials were dried; several furnaces were used for these purposes: a rotary kiln, multiple-hearth vertical furnaces, and small single-hearth furnaces.

All roasted materials were used as feed in the refinery. Recycle materials of significantly different isotopic assays were segregated throughout processing and in storage. The size of production equipment limited processing of enriched materials to 1.25% ^{235}U. Filtration equipment was used for reclaiming low-level solid waste for drying, packaging, and shipment off the site for burial.

Various thorium residues were processed through the Plant 8 oxalate system to thorium hydroxide to return them to the production stream. Residues were digested in hydrochloric acid and the solution was filtered on a rotary vacuum filter. The filtrate was pumped to a precipitation tank and mixed with oxalic acid. Thorium oxalate precipitated out of the solution. The thorium oxalate precipitate was filtered, slurried, and reverted with sodium hydroxide solution to thorium hydroxide. The thorium hydroxide was filtered on a rotary vacuum filter and the solution was recycled back to the precipitation tank. The filter cake was calcined in a multiple hearth furnace called the uranium ammonium phosphate furnace. The dried thorium hydroxide was digested in the Pilot Plant digestion system. Approximately 310 metric tons of thorium as thorium hydroxide were produced through the Plant 8 oxalate system.

Thorium hydroxide was produced in Plant 8 for 6 months in 1966 in the reversion system. Thorium tetrafluoride was reverted to thorium hydroxide by heating it in a reverter tube with hydrofluoric acid. The offgas from the reverter was neutralized in a caustic scrubber. Approximately 59 metric tons of thorium in the form of thorium hydroxide were produced by this system.

2.2.8.2 Radiation Sources

Radioactive sources in Plant 8 included uranium, recycled uranium metal, and thorium compounds.

Radioactive thorium compounds are contained in one silo and in two sections of a common bin structure at Plant 8. The silo contents are primarily thorium oxide, thorium hydroxide, and from 25% to 50% diatomaceous earth. Other thorium compounds in small quantities might be present. In addition, some residual uranium compounds are in the silo.

Radiation measured at the surface of the thorium silo ranges from 3 to 40 mR/hr. The area above and immediately around the silo is an airborne radioactivity area. The radiation level of the silo gradually increases from ground level (3 mR/hr) to about 20 mR/hr at the bottom conical section. The radiation level gradually increases to about 37 mR/hr at the top of the thorium fill level in the silo, and then decreases to 7 mR/hr at the top of the silo. The maximum surface radiation level is 55 mR/hr at the cone/cylinder interface; however, radiation levels as high as 70 mR/hr have been observed.

A spot check of the thorium bin shows maximum surface radiation of 40 mR/hr. The surface gamma radiation measures 11 mR/hr at the bottom of the bin and 13 mR/hr at the top of the bin. The maximum surface radiation is 45 mR/hr at the bin/hopper junction.

Results of an exposure study of Plant 8 personnel to airborne radioactivity by operation or location during 1956 and 1957 are listed in Table 2-14a. Table 2-14b provides the estimated potential annual uranium intakes by Plant 8 worker by years. Table 2-14c provides the estimated thorium intakes.

Table 2-14a. Plant 8 average airborne radioactivity concentrations by operations or locations.

Operation or location	Type sample[b]	Ave. 1956 and 1957 Data		
		× MAC[a]	Conc. α dpm/m^3	Conc. w/Respirator[c] Bq/m^3
Outside				
Outside Williams Mill	GA	44.30	3101.00	1.03E+00
Breaking salt at outside mill	BZ	30.80	2156.00	7.19E-01
Shoveling onto conveyor at outside mill	BZ	137.80	9646.00	3.22E+00
Changing drums at outside mill	BZ	122.90	8603.00	2.87E+00
C-liner flow				
Juice hopper area	GA	0.65	45.50	7.58E-01
Conveyor silo to calciner area	GA	1.48	103.60	1.73E+00
Conveyor silo to bucket elevator	GA	3.48	243.60	4.06E+00
Williams Mill, 2nd floor	GA	0.65	45.50	7.58E-01
Calciner furnace, drum dumping area	GA	2.12	148.05	2.47E+00
Rotex dumping station area	GA	0.65	45.50	7.58E-01
Rotex drumming station area	GA	0.74	51.80	8.63E-01
Dumping drum of C-liner	BZ	8.21	574.35	1.91E-01
Feeding material to Rotex	BZ	9.71	679.35	2.26E-01
Changing drums at Rotex drumming station	BZ	8.02	561.40	1.87E-01
Checking Rotex drum for fullness	BZ	4.57	319.90	1.07E-01
Box furnace				
Box furnace area	GA	1.56	109.20	1.82E+00
Feeding box furnace	BZ	1.09	75.95	1.27E+00
Checking drum for fullness	BZ	6.99	489.30	1.63E-01
Changing drums at box furnace	BZ	4.95	346.50	1.16E-01
Oxidation furnace				
Oxidation furnace area, 2nd floor	GA	1.56	109.20	1.82E+00
Smoking area, 1st floor	GA	1.48	103.60	1.73E+00
Spreading material on feed tray & removing foreign objects	BZ	1.77	123.90	4.13E-02
Feeding oxidation furnace	BZ	2.05	143.15	4.77E-02
Checking drum for fullness	BZ	2.85	199.50	6.65E-02
Changing drums at oxidation furnace	BZ	4.45	311.15	1.04E-01
Muffle furnace				
Muffle furnace area, 1st floor	GA	1.03	72.10	1.20E+00
Muffle furnace area, 2nd floor	GA	0.60	41.65	6.94E-01

Operation or location	Type sample[b]	Ave. 1956 and 1957 Data		
		× MAC[a]	Conc. α dpm/m^3	Conc. w/Respirator[c] Bq/m^3
Charging muffle furnace	BZ	29.04	2032.80	6.78E-01
Hoeing material in muffle furnace	BZ	2.98	208.25	6.94E-02
Checking drum for fullness	BZ	32.05	2243.15	7.48E-01
Changing drums at canning station	BZ	121.25	8487.50	2.83E+00
Graphite furnace				
Graphite furnace area, 2nd floor	GA	0.84	58.80	9.80E-01
Dumping feed material on tray	BZ	4.60	322.00	1.07E-01
Charging (chips and turnings)	BZ	7.20	504.00	1.68E-01
Pushing chips into furnace, south side	BZ	1.08	75.60	2.52E-02
Hoeing material in furnace	BZ	0.92	64.05	2.14E-02
Checking drums for fullness	BZ	1.36	95.20	3.17E-02
Changing drums	BZ	24.44	1710.45	5.70E-01
Rotary kiln				
Rotary kiln area, 1st floor	GA	2.80	196.00	3.27E+00
Smoking area by panel board for kiln	GA	0.67	46.90	7.82E-01
Feed tray area	GA	0.18	12.60	4.20E-03
Feeding kiln	BZ	1.20	83.65	2.79E-02
Checking drum for fullness at “scalping” canning station	BZ	5.83	407.75	1.36E-01
Changing drum at kiln scalping station	BZ	24.05	1683.50	5.61E-01
Checking drum for fullness at product canning station	BZ	9.90	693.00	2.31E-01
Changing drums at product canning station	BZ	18.01	1260.70	4.20E-01
Dumping through kiln drum dumper	BZ	4.59	321.30	1.07E-01
Green salt reverter				
Dumping area	GA	1.83	127.75	2.13E+00
Mezzanine area	GA	1.98	138.25	2.30E+00
Canning station area	GA	2.17	151.90	2.53E+00
Feeding at reverter dumping station	BZ	9.04	632.80	2.11E-01
Checking drum for fullness at canning station	BZ	32.51	2275.70	7.59E-01
Sampling oxide at canning station	BZ	12.43	870.10	2.90E-01
Changing drums at reverter canning station	BZ	155.37	10875.90	3.63E+00
Wet area, 1st floor				
Dump trailer area	GA	0.20	14.00	2.33E-01
Foreman’s office	GA	0.14	9.45	1.58E-01
Control room	GA	0.12	8.40	1.40E-01
Washrooms	GA	0.31	21.70	3.62E-01
Moyno pump area	GA	0.71	49.70	8.28E-01
Denver crusher canning station area	GA	0.17	11.90	1.98E-01
Digester area, 1st floor	GA	0.32	22.40	3.73E-01
Sampling dump trailer	BZ	0.33	23.10	3.85E-01
Wet area, 2nd floor				
Surge and weigh hopper area	GA	0.17	11.90	1.98E-01
Conveyor area, surge hopper to digest tanks	GA	0.97	67.90	1.13E+00
Denver crusher area	GA	0.34	23.80	3.97E-01
Oliver filter area	GA	0.50	34.65	5.78E-01
Nimco filter area	GA	0.17	11.55	1.93E-01
Smoking areas:			0.00	0.00E+00
By weigh hopper	GA	1.29	89.95	1.50E+00
By Oliver filter	GA	0.70	48.65	8.11E-01
In front of generator room	GA	0.21	14.35	2.39E-01
Raking material on Oliver filter	BZ	0.63	44.10	7.35E-01

Operation or location	Type sample[b]	Ave. 1956 and 1957 Data		
		× MAC[a]	Conc. α dpm/m^3	Conc. w/Respirator[c] Bq/m^3
Diuranate furnace			0.00	0.00E+00
Canning station area	GA	0.42	29.40	4.90E-01
Smoking area panel board	GA	0.07	4.90	8.17E-02
Second floor	GA	1.35	94.50	1.58E+00
Pushing material off top hearth	BZ	0.63	44.10	1.47E-02
Checking drum for fullness	BZ	3.84	268.45	8.95E-02
Scoop sampling oxide at canning station	BZ	21.44	1500.45	5.00E-01
Changing drum	BZ	49.31	3451.70	1.15E+00
Plate-frame filter press				
General area, 1st floor	GA	0.30	21.00	3.50E-01
Scraping cake from filter leaves	BZ	1.52	106.40	3.55E-02
Shoveling cake into drums	BZ	1.26	87.85	2.93E-02
Reassembling press	BZ	0.34	23.80	3.97E-01
Maintenance Area, 2nd floor	GA	0.09	6.30	1.05E-01
Lime and Precoat Make-up Tank Area	GA	0.11	7.70	1.28E-01
Centrifuge				
General area, 1st floor	GA	0.47	32.90	5.48E-01
Charging area, 2nd floor	GA	1.83	128.10	2.14E+00
Charging with contaminated oil	BZ	5.81	406.70	1.36E-01
Operating controls, 1st floor	BZ			
Leaching tank				
General area, 1st floor	GA	0.17	11.90	1.98E-01
General area, 2nd floor	GA	0.10	7.00	1.17E-01
Charging leach tank	BZ	0.31	21.70	3.62E-01
Average over Plant 8 areas and operations		11.23	674.20	7.56E-01

[a] Maximum Allowable Concentration (MAC) - 70 α d/m per meter^3
[b] GA = General Area BZ = Breathing Zone
[c] A Decontamination Factor (DF) of 50 for wearing respirator was applied to Breathing Zone (BZ) concentrations for selected process activities.

Air samples from the top of the thorium silo indicate thoron daughter concentrations as high as 71 WLs (WL defined as 1.3 x 10^5 MeV of potential alpha radiation per liter of air from radon daughter products without regard to the radon and daughter equilibrium). Air samples taken at the top of the silo indicate a thoron daughter (^{220}Rn) concentration of 71 times the Acceptable Working Concentration or 71 WL. The area above and immediately around the thorium silo is an airborne radioactivity area.

Air samples at the surface of the thorium bin indicated a thoron daughter concentration of 0.44 WL. The airborne concentration of thoron daughters in air samples taken from the top of the bin is 0.44 WL. Concentrations above 0.3 WL cause the area to be declared an airborne radiation area.

Table 2-14b provides a summary of the projected annual uranium intake that was estimated based on exposures to Plant 8 workers.

Table 2-14b. Projected annual estimated uranium intake by Plant 8 workers.

Years	Adjustment Factor[a] 1956 and 1957 Data	Average Annual Uranium Intakes[b] Bq/yr
1953-1954	0.7	1.27E+03
1955-1964	1.0	1.81E+03
1965-1968	0.8	1.45E+03
1969-1971	1.0	1.81E+03
1972-1975	0.6	1.09E+03
1976-1981	0.25	4.54E+02
1982-1984	0.74	1.34E+03

[a] The measured airborne radioactivity concentrations are adjusted for other years than the year in which the measurements are made, in accordance with the percentage of process system throughput capacity in one shift. In absence of specific throughput information, Appendix 2A is used as the default model for FEMP production rates for the derivation of the adjustment factors.

[b] Radionuclide (e.g., Pu, Np, Tc and U isotopes) radioactivity fractions for recycled uranium is given in Table 2-54.

Table 2-14c. Projected annual estimated thorium intake by Plant 8 workers.

Years	Adjustment Factor[a] 1956 and 1957 U Data	Average Thorium Conc. Bq/m^3	Average Annual Thorium Intakes Bq/yr
1966	3.39E-03	2.56E-03	6.14E+00
1969	1.32E-02	9.97E-03	2.39E+01
1970	2.54E-02	1.92E-02	4.62E+01
1971	3.05E-02	2.31E-02	5.55E+01

[a] The estimated uranium concentrations are adjusted to obtain thorium concentrations in accordance with the ratio of thorium/uranium emission estimates. Emission estimates are in Appendix 2B.

2.2.9 Plant 9 – Special Products Plant

Construction of the Special Products Plant was complete in 1954; the facility had a ground floor area of 48,500 sq. ft. This facility was originally designed and constructed as a thorium metal production plant. The two basic processes, hydrofluoric acid precipitation of thorium fluoride and induction dezincing and melting, which were used to start the plant, were not able to produce a pure metal. However, improvement in production techniques permitted the eventual development of an oxalate precipitation process capable of producing pure thorium metal. The process began with the dissolution of solid thorium nitrate tetrahydrate in nitric acid. Hydrofluoric acid was added to the solution to precipitate a wet thorium tetrafluoride (ThF_4). The ThF_4 was dried in a predryer and a retort dryer and then was pulverized. The pulverized ThF_4 was blended with calcium metal and zinc chloride and placed in a refractory lined furnace pot. Thorium tetrafluoride was coreduced by the calcium to form a zinc-thorium derby, from which the zinc was removed and remelted in a vacuum furnace. The resulting 500-kilogram thorium metal ingot was machined to produce the final thorium metal product. An estimated 380 metric tons of thorium metal were produced in Plant 9 from 1954 through 1955.

2.2.9.1 Processes and Activities

Because thorium processing was infrequent and in small amounts, the primary function of the Special Products Plant became casting larger ingots than those produced in Plant 5 and machining uranium metal pieces for extrusion. The principal capabilities of the Special Products Plant were:

- Casting enriched uranium derbies and recycle metal scrap into large-diameter ingots for N-Reactor
- Machining as-cast ingots and billets for extrusion
- Cleaning depleted uranium derbies for offsite shipment
- Decladding unirradiated copper-zirconium fuel cores

Operations in the Special Products Plant primarily involved machining uranium metal pieces and casting enriched uranium ingots up to 13 inches in diameter and 25 inches in length, and weighing up to 900 kg. Shrinkage cavities and impurities were removed by cropping the top section, as was done with smaller ingots. Cropped ingots from both plants were center-drilled on a unique LeBlond-Carlstadt Rapid Boring machine. Surface machining was performed on standard lathes.

The ingot bore process (12.8 min. per ingot) involved the following operations:

1. Operator presses BORE button to lower loader, then COOLANT START button. Check for good seal, then presses SPINDLE ON, checks RPM, and starts bore by pressing FEED forward button (all < 1 minute). During bore, operator continually monitors gauges for tool breakage and coolant pressure levels, and performs the following tasks:
2. Move the bored, inspected ingot from “inspection” stand to skid (45 sec).
3. Move a new ingot to “preparation” stand and knocks off “fins,” which might prevent proper chucking (1 min).
4. Replace chip drum when full (after every two ingots, 1.5 min).
5. Measure and mark lengths, removes isotopic labels, and record identity numbers of skid of new ingots (3 min/4 ingots).

The ingot exchange process (5.7 min. per ingot) involved the following operations:

1. By observing pressure dials, operator determines that boring is completed.
2. STOP the machine, RETRACT tool, press LOAD button, and slide back the splash guard. Unclamp and unchuck ingot, check core clearance, move hoist in, and clamp and lift ingot.
3. Use a rod to push a rag through the bore to wipe out oil and move ingot to inspection stand. Inspect tool and remove core to place in storage drum.
4. A new ingot is hoisted from “preparation” stand and loaded into position. Operator clamps in, tightens chuck, and closes splash guard.

The NPR Saw operation (performed only on the second shift) consisted of five steps, namely positioning, sawing, stamping, weighing, and crating or storing of ingot material. After the ingots were separated within the separation booth, they were positioned manually on a conveyor extending from the separation booth to the saw. The ingots were pushed along the conveyor to a point near the saw before they could be automatically positioned for sawing off the "crop" end. After the "crop" end was sawed, at least two additional cuts, and sometimes three, were made on each ingot. The total time for each ingot in the saw operation was approximately 1 hour. The "crop" end and other sample cuts were placed manually in a wooden box. The ingots were then hoisted onto a skid for storage nearby.

All ingots cast in the Special Products Plant were for supplying the enriched N-Reactor fuel core requirement for the reactors at the Hanford Site. Machined ingots weighed as much as 520 kg and underwent heat-treating in the Metals Fabrication Plant.

A chemical decladding process, called Zirnlo, was performed in the Special Products Plant. Reject coextrusion sections from the cladding operation at Hanford were immersed in dilute nitric acid to remove the outer copper layer that served as a lubricant during coextrusion of Zircaloy-2 and uranium. The decoppered coextrusion sections were treated with dilute HF to remove the Zircaloy-2 jacket that encased the uranium metal core. The totally declad bare uranium metal cores were recycled to the casting operation for remelting to ingot form.

2.2.9.2 Radiation Sources

Radioactive sources in the Special Products Plant were recycled uranium and uranium metal, and thorium metal and compounds.

Results of the gamma fluxes recorded at various stations applicable to Plant 9 from the radiation field characterization and radiological equipment evaluation at the FEMP are listed in Table 2-15.

Table 2-15. Plant 9 gamma fluxes.

Spectrum number	Location	Integrated gamma flux (photons/cm^2 sec)		
		30-225 keV	675-1050 keV	Ratio
388411	Just inside south entrance	253	43	5.9
388412	Lathe work station northeast corner	424	76	5.6
388415	West wing, southwest hot area	708	72	9.8
388416	Just outside south entrance by exhaust fan	776	165	4.7
388402	HP change room	5	<0.4	12.5
388419	HP change room	5	<0.5	10.0

LeBlonde Rapid Bore Operation Doses

An investigation was performed early in 1981 to determine elements of the Plant 9 LeBlonde Rapid Bore operation that contributed to operator external (beta-gamma) radiation exposure and to make quantitative estimates of these elements to recommend means for exposure reduction under ALAP goals. The results (skin doses) are listed in Table 2-16.

Table 2-16. Plant 9 LeBlonde Rapid Bore skin doses.

Operation	Average dose rate (mR/hr)	Skin dose (mR)		
		Per ingot	Per shift (22 ingot)	Per month (21 shifts)
Bore	2.23	2.23	49.1	1,030
Exchange	14.6	1.39	30.6	642
Total	11.7	3.62	79.7	1,672

NPR Saw Operation Doses
An external radiation survey for the NPR Saw Station in Plant 9 had resulted in the following measurements throughout the NPR saw area:

Conveyor from Separation Booth to Saw (4 NPR 11-in. ingots)
Contact – 200 mrad/hr β
Side of ingots – 1,000 – 2,000 mrad/hr β, 5 mR/hr γ
Crop end of ingots – 20 – 30 mR/hr γ
At 1 ft. away – 100 – 300 mrad/hr β, 3.0 –5.0 mR/hr γ

Saw Station (11-in. NPR ingot within Saw; metal shield approximately 4 ft high and 2 ft was directly in front of saw)
Behind shield – 0.5 mrads/hr β and 0.5 mR/hr γ
Above shield (working distance – chest level) – 25 mrads/hr β and 0.8 mR/hr γ

General Saw and Storage Area
Saw area – 5-20 mrads/hr β; 2.0 – 3.0 mR/hr γ
Storage area – 20-30 mrads/hr β; 3.0-4.0 mR/hr γ

The following table provides the resulting radiation exposure data for several work assignments performed by the operator:

Sawing extrusions made from 11-inch ingots	11 mR (3 days avg.)
Sawing 11 inch NPR ingots	33.4 mR (5 days avg.)
Crushing – briq. area	10 mR
Pickling - briq. area	5 mR
Total	59.4 mR γ and
	259 mrads β (24 days avg.)

Dose Rates at Plant 9 Locations
Surveys of external radiation levels at the Plant 9 remelt, ingot separation, charging and burnout areas were conducted in February 1963. Results are as follows:

Remelt Area
General work areas - 10 mrad/hr.
Working distance in the bottom remelt areas – 15 mrad/hr
Working distance while vacuum cleaning the NPR bottom mold tank sections – 40 mrad/hr

Charging Station
The crucible cleaning and coating operation – 100 mrad/hr

Burnout Station
Radiation inside the burnout – 40 mrad/hr
Bottom north side of the burnout enclosure general background – 15 mrad/hr.

Table 2-17a lists airborne radioactive material concentrations for various operations and locations at Plant 9. Table 2-17b provides the estimated potential annual uranium intakes by Plant 9 worker by years. Table 2-17c provides the estimated thorium intakes.

Table 2-17a. Plant 9 airborne radioactive dust concentration by operation or location. (year data taken as indicated)

Operation or location	Ave. Conc. (α dpm/m^3)	Conc. w/Respirator[a] Bq/m^3
Wet area (thorium): (1955 data)		
Operator hand scooping white salt from 30-gal drum into pre-dryer	1,394	4.65E-01
Emptying cellophane bag of white salt into predryer	59	1.97E-02
Over drum of wet thorium oxalate while operator hand scoops from drum to predryer	1,379	4.60E-01
In northwest corner of area while hand-filling predryer	1,056	3.52E-01
Over opening to predryer. Steam and fumes evolving from predryer. No hand loading of predryer	4,811	1.60E+00
North end of the building next to sump area: (1959 data)		
Operator removing slugs from box placing on angle iron rest, deburring and placing slugs back in box. No respirator worn	277	4.62E+00
Mold cleaning station: (1960 data)		
Operator cleaning mold and coating with $MgZrO_3$. Respirator worn	143	4.77E-02
Ingot stamping station: (1960 data)		0.00E+00
Pushing ingot down conveyor	140	4.67E-02
Stamping crop end	6,840	2.28E+00
Breaking sample piece off ingot, stamping, and breaking in two.	1,976	6.59E-01
Pot delidding station: (1960 data)		0.00E+00
Delidding pot (prior to ventilated)	1,190	3.97E-01
Delidding pot (ventilated)	281	9.37E-02
East Pad, south of the maintenance shop—mortar and brick removal from remelt furnace coil (done twice each week)		
Breaking brick and mortar with hammer and chisel, and picking loose brick from inside coil and tossing into drum. (Respirator worn)	24,932	8.31E+00
Laborer shoveling brick and mortar residue from bottom of tank. (Respirator worn)	67,039	2.23E+01
Furnace charging and capping area: (1963 data)		
Furnace pot capping---operator scoop MgF2 from the drum into furnace pot.	150	5.00E-02
Capping operator exposes to	620	2.07E-01
Plant 9 Zirnlo operation: 270 pounds of crushed fuel elements were manually transferred from 55-gal drum to Zirnlo basket and back. This operation was infrequent and of short duration (1980 data)		
Drum unloading (General Area)	6.73	1.12E-01
(Breathing Zone)		
Drum loading (General Area)	21.88	3.65E-01
(Breathing Zone)		
Gisholt “5L” ingot sampling lathe located near the Zirnlo: (1981 data)		
Before modification to reduce cutting fumes		
Inventory table northwest of lathe (general area)	59	9.83E-01
End of wall at south end of lathe	56.7	9.45E-01
Bench & chair west of lathe where operator rests	39.3	6.55E-01
On lathe operator (breathing zone) 11/20	695	2.32E-01
On lathe tool bench	35	5.83E-01
Behind lathe near chip pile	73	1.22E+00

Operation or location	Ave. Conc. (α dpm/m^3)	Conc. w/Respirator[a] Bq/m^3
On lathe operator (breathing zone) 12/1	270	9.00E-02
After modification to reduce cutting fumes		
On operator	191	6.37E-02
On ticket table north of lathe	42.4	1.41E-02
On lathe tool feed bench near where operator stands when checking tool and cleaning chips off tool	154.8	5.16E-02
On vacuum barrel 25 ft southwest of lathe tool rest near south aisle	33	5.50E-01
On south end of ingot conveyor east lathe	58.8	9.80E-01

[a] A Decontamination Factor (DF) of 50 for wearing respirator was applied to Breathing Zone (BZ) concentrations for selected process activities.

Table 2-17b. Projected annual estimated uranium intake by Plant 9 workers.

Years	Adjustment Factors[a]		Average Uranium Conc. Bq/m^3	Average Annual Uranium Intakes[b] Bq/yr[b]
	1955-1963 Data	1981 Data		
1957-1964	1.0	4.0	1.78E+00	4.26E+03
1965-1968	0.9	3.6	1.60E+00	3.84E+03
1969-1971	1.0	4.0	1.78E+00	4.26E+03
1972-1975	0.6	2.4	1.07E+00	2.56E+03
1976-1981	0.25	1.0	4.44E-01	1.07E+03
1982-1984	0.74	2.9	1.30E+00	3.13E+03
1985-1988	0.5	1.0	7.01E-01	1.68E+03

[a] The measured airborne radioactivity concentrations are adjusted for other years than the year in which the measurements are made, in accordance with the percentage of process system throughput capacity in one shift. In absence of specific throughput information, Appendix 2A is used as the default model for FEMP production rates for the derivation of the adjustment factors. The " *FEMP uranium emissions summary by plant*" in Appendix 2B is used to identify operating years. 1973 data were taken at the end of a campaign, since then, it is assumed that the measured concentrations were resulting from full system capacity.

[b] Radionuclide (e.g., Pu, Np, Tc and U isotopes) radioactivity fractions for recycled uranium is given in Table 2-54.

Table 2-17c. Projected annual estimated thorium intake by Plant 9 workers.

Years	Adjustment Factor[a]	Average Thorium Conc.[b] Bq/m^3	Average Annual Thorium Intakes Bq/yr
1954	1.0	7.28E-02	1.75E+02
1955	1.0	7.28E-02	1.75E+02

[a] The thorium concentrations for the casting operations are assumed to be the same in weight/vol. as those estimated for uranium in 1954 and 1955.

[b] The thorium concentrations in Bq/m^3 are obtained by multiplying U concentrations by the Th/U specific activity ratio.

2.3 WASTE MANAGEMENT FACILITIES ACTIVITIES AND PROCESSES

Figure 2-1 shows locations of waste treatment and storage facilities in and outside the fenced production area of the FEMP. The Waste Storage Area outside the production area includes six low-level radioactive waste storage pits, two earthen-bermed concrete silos containing K-65 residues (high specific activity, low-level radium-bearing residues), one concrete silo containing metal oxides,

and affected adjoining areas. It also includes two fly ash piles approximately 3,000 feet south-southwest of the waste storage area, as well as the burn pit between Pits 3 and 4.

2.3.1 Production Wastes

A wide variety of chemical and metallurgical processes were used at FEMP to produce high-purity uranium metal. As a result, various waste forms were generated. Both solid and liquid wastes were produced. Radioactive and mixed wastes from FEMP production processes included wet filter cake, sludge, neutralized raffinate, dry slag, ash, metallic uranium fines, oxides, and miscellaneous trash.

Dry filter cakes from the Recovery Plant, resulting from the filtration of raffinate and sludge that accumulated in the general sump, are stored in drums for disposal at the Nevada Test Site (NTS). Wet filter cakes were drummed and stored on the FEMP and later (after 1986), the wet filter cakes were further dried in a rotary hearth furnace and drummed for disposal at NTS.

Combustible residues, sewage sludge, graphite, and oils that contain low-level radioactive wastes were treated as process residues and incinerated in various facilities. Uranium was recovered from the generated ash in the Recovery Plant of the refinery.

Noncombustible solid wastes, including clothing and gloves, generated at the FEMP have been boxed or drummed for offsite shipment and disposal at NTS. The uranium content of these wastes is low and uranium recovery is not feasible.

The chemical composition of the production wastes is quite varied, but major components are metal oxides and nitrates of copper, aluminum and iron; calcium oxide; free uranium and uranium in various oxidation states; magnesium fluoride; and traces of free magnesium.

Several radionuclides including uranium and thorium, small quantities of fission products (^{90}Sr, ^{137}Cs, and ^{99}Tc), transuranics (neptunium and plutonium), and non-uranics are present in the radioactive and mixed wastes.

The uranium content of the various waste streams varies from about 0.0005 grams U/gram of solids in the neutralized refinery raffinate and slag leach filter cake to 80% to 100% U in discarded metal and oxides. The percent enrichment in ^{235}U is 0.2% to 1.1% in the waste materials.

Since 1972, the FEMP has served as the thorium materials repository for DOE. Approximately two-thirds of the material in the repository was processed at the FEMP. The remainder originated at other DOE facilities. An inventory of thorium is stored in the production areas of the site, and some thorium is in relatively high-traffic areas (Plant 8 silo). Table 2-18 lists the FEMP thorium inventory as of 1988.

Table 2-18. Location and number of thorium drums*.

Location	Thorium containers
Building 65	5,836 drums
Pilot Plant	1,313 drums
Building 67	382 drums, 5,500 cans
Building 64	180 cans
TOTAL	13,211

* As of 1988.

Many containers have been removed from the site during the remediation process. The remaining thorium (approximately 500,000 lb) is stored in approximately 200 metal boxes. The thorium is primarily a mixture of thorium metal, thorium oxides, and process residues.

2.3.2 Production Area Waste Treatment and Storage Facilities

The waste treatment, storage, and management facilities directly associated with FEMP production operations include the Thorium Overpacking Operation, Ferrous Metal Scrap Pile, Copper Scrap Pile, Waste Oil Storage Pad, Oil Burner, Plant 1 Storage Pad, Solid Waste Incinerator, Pilot Plant Tank Farm, Pilot Plant Warehouse, KC-2 Warehouse, and Refinery Storage Pad.

2.3.2.1 Thorium Buildings and Overpacking Operations

The thorium buildings (Buildings 64, 65, 67, and 68) were constructed with preengineered warehouse/storage buildings. During the 1990s, drums of thorium stored in various plant locations, including those in Building 65 and 67, were overpacked and transferred to Buildings 64 and 78 for interim storage and eventual offsite shipment. Structurally unsound drums were placed inside larger containers by overpacking. The overpacked and structurally sound drums were transferred to Buildings 64 and 78 and subsequently placed in strong tight containers (STCs) suitable for offsite shipment.

The stored thorium compounds (thorium hydroxide, oxide, and oxalates) came from two separate time periods. In the 1950s, thorium metal was produced for the nuclear aircraft program that was cancelled in 1961. In the mid-1960s, thorium oxides were produced for the Light Water Breeder Reactor Program. The stored materials are out-of-specification production runs, process byproducts, or excess materials returned from downstream production facilities when the materials were no longer required.

To assess exposures to radiation associated with thorium operations (overpacking or storage), all of the stored thorium is assumed to be ^{232}Th. It is considered to be 35 years old for the purpose of determining daughter isotope concentrations. The average total thorium inventory in a typical drum is approximately 70 kg, and the dispersible component of the thorium inventory in a drum is approximately 57 kg.

External gamma radiation exposure can be as great as 70 mR/hr from a drum. Table 2-19 lists external radiation by job and the overpacking operational activities.

Table 2-19. Dose estimates for thorium overpacking operations.

Operation/personnel	Dose rates (mR/hr) w/o shieldg/w/shieldg/bkgd[d]	Handling time (min.)	Unshielded dose (mR/drum)	Shielded dose (mR/drum)
Container handling	50 / 3.0 / 7.0	10[a]		
Fork-truck operator			9.5	0.4
Overpacking material identification.	60 / 10.0 / 7.0	30[b]		
Overpacking operator			26.6	1.1
Laborer			7.1	0.3
Th overpack handling.	40 / 1.0 / 7.0	10[c]		
Fork-truck operator			2.6	0.06

a. Time for handling per drum, that is, time from initial drum pickup to placement on the conveyor. Pickup 5 min, Transport 2 min, Conveyor Placement 2 min.

b. If a drum does not require repackaging or sampling, identification/placement into six-packs is estimated to take 20 min. The estimated majority (85%) of the drums would be in this condition. Drums requiring sampling and/or repackaging are estimated to require 40 min. An estimated 10% of the drums would be in this condition. Potentially pyrophoric drums require sampling and special handling. The estimated average handling time for the remaining 10% of the drums is 50 min per drum. The average drum handling time is estimated to take 26 min. to place into six-packs. To this average handling time is added 4 min to account for urethane foam application, foam trimming, and six-pack lid emplacement. Therefore, the total average handling time is 30 min.

c. The thorium overpack handling time is the estimated elapsed time from six-pack pickup by the fork-truck at the portable shield area to placement of the six-pack in Building 64.
d. Shielding provided at the fork-truck operator cage and in the jib crane area for worker to stand behind. Background dose rate is referred to as ambient dose rate in the building.

In relation to gamma exposure to other workers of the thorium overpacking operation, the exposure data from1992 job-specific thermoluminescent dosimeters for overpacking operations in Buildings 68 and 67 (800 drums) in Table 2-20 can be used for dose estimation.

Table 2-20. Average annual exposure for Building 68 and 67 overpacking staff (800 drums).

Total staff	Mean dose	Dose (mrem)				
		0-10	>10-50	>50-100	>100-500	>500-1000
93 (100%)	73 mrem	31%	40%	13%	13%	3%

The source terms for the estimation of internal dose due to normal thorium dust inhalation are based on expected events that could release dispersible thorium dust in operating areas. Table 2-21 is a summary of dispersible thorium in a typical thorium drum.

Table 2-22 lists expected airborne thorium as a result of the overpacking operation on an annual basis.

Table 2-21. Summary of dispersible thorium in a typical thorium drum.

Locations	No. of drums	Thorium (grams)	gm/drum[a]
Building 64	180	1.23E+05	6.83E+02
Building 65	5,599	3.22E+08	5.75E+04
Building 64 overpacked	240	1.90E+07	7.91E+04
Total	6,019	3.41E+08	5.66E+04

[a] Average g/drum is the total grams divided by total drums.

Table 2-22. Expected airborne thorium during the overpacking operation.

Event	Frequency (event/year)	Th released (gm/event)[a]	Annual release (gm/year)
Fork impact	17	1.62E+01	2.75E+02
Fork drop	17	3.23E+01	5.50E+02
Physical degradation	42	6.90E-01	2.91E+01
Miscellaneous	1,358	1.62E-01	2.19E+02
Total			1.07E+03

[a] This includes the applicable ARFs

Based on ventilation rate and reduction of airborne dust by the filtration systems, the estimated average thorium dust concentration is 1.97×10^{-5} gm/m^3.

2.3.2.2 Ferrous Metal Scrap Pile

The FEMP had approximately 5,000 metric tons of metallic scrap containing above-background levels of uranium. This material is stored on a controlled curbed pad on the northeast corner of the site. The scrap pile consists primarily of ferrous material; the remainder is a mixture of aluminum, stainless steel, copper, brass, and nickel. The scrap includes, but is not limited to, vessels, wiring, cable, duct, pipe, tubing, valves, grating, sheets, plates, and miscellaneous abandoned equipment. Some materials at the facility are classified as low-level radioactive waste.

2.3.2.3 Pilot Plant Tank Farm

The Pilot Plant Tank Farm is the location of the FEMP hazardous waste tank container facility. The facility consists of two 10,000-gallon stainless-steel storage tanks (T-5 and T-6) on a concrete pad surrounded by a concrete containment dike.

The FEMP inventory of these tanks is 13,000 gallons or 136,874 lb of spent degreasing solvents. Annual generation averages approximately 110 gallons (1300 lbs.) of RMI[1] degreasing solvents (45% methylene chloride, 55% perchloroethylene) and 110 gallons (1110 lbs.) of 1,1,1-trichloroethylene

2.3.2.4 Pilot Plant Warehouse

The Pilot Plant Warehouse is a totally enclosed and roofed warehouse facility with a poured concrete floor and side walls, so no rain falls directly on the storage area. The storage area for hazardous waste at the Pilot Plant Warehouse is 7 ft wide by 62 ft long.

The Pilot Plant Warehouse container storage facility was used as the storage area for waste barium chloride salts shipped to the FEMP from RMI in drum containers with U.S. Department of Transportation (DOT) Specification numbers 17H. Waste salts are generated as a result of RMI heat-treatment operations. They are a spent eutectic salt mixture containing barium chloride (45%), potassium chloride (32.5%), and sodium chloride (22.5%). One-hundred and sixty-seven drums of barium chloride are stored at this facility: 70 drums of barium chloride, 13 drums of trash contaminated with barium chloride, 26 drums of floor sweepings with barium chloride, and 58 drums of salt brick.

2.3.2.5 KC-2 Warehouse

The KC-2 Warehouse container facility is a curbed storage facility 42 ft long by 7 ft wide in Bay No. 5 of the warehouse. The warehouse is roofed, with a poured concrete floor, concrete block divided (side) walls, and chain-link front and back walls.

Spent solvents generated on the site (1,1,1-trichloroethane), as well as spent solvents generated off the site (45% methylene chloride/55% perchloroethylene) at the RMI facility, were generated as a result of degreasing operations. These solvents might temporarily be stored at the KC-2 Warehouse container storage facility until the liquid waste can be transferred to the bulk storage tanks at the Pilot Plant Tank Farm.

The KC-2 Warehouse (Bay 5) is used to store polychlorinated biphenyls (PCBs). Although PCBs are regulated by the Toxic Substance Control Act, PCB wastes at the FEMP also contain uranium and are classified as mixed wastes. Solvent still bottoms and sludges, and PCB-containing capacitors are the two types of PCB-contaminated wastes stored at the KC-2 Warehouse.

The inventory of PCB still bottoms and sludges is approximately 20,000 lb (37 55-gallon drums) and two 55-gallon drums of absorbent from cleanup operations. In addition, 19 55-gallon drums of capacitors, one drum of rags from capacitor cleanup, one drum of PCB-containing water (30 gallons) and one drum of laboratory samples are stored at this warehouse; this totals 51 drums of PCB-contaminated materials.

[1] From the Reactive Metals, Inc., DOE support site in Ashtabula, Ohio.

2.3.2.6 Refinery Storage Pad

In addition to the other production storage areas, a controlled pad at the refinery (Plants 2/3) is used for storage of waste oil and oil sludges. The FEMP inventory at the Refinery Storage Pad is 900 55-gal drums of waste cutting and cooling oils. Approximately one 55-gallon drum of waste oil is generated per day at the FEMP. In addition to the waste oil, 48 drums of oil sludges are stored at the Refinery Storage Pad.

2.3.3 Waste Facilities Outside Production Area

Waste management facilities outside the FEMP Production Area include the Storage Silos, Low-Level Radioactive Waste Pits, Underground Storage Tanks, and Sanitary Landfill.

2.3.3.1 Storage Silos

Four above ground silos (Silos 1 to 4) used for storage of radium-bearing residues from the uranium ore processing are on the west side of the FEMP.

Silos 1 & 2 (K-65 Silos)
The two above-ground K-65 silos were constructed in 1955. They were used for storage of radium-bearing residues, a byproduct of uranium ore processing. The silos are of cylindrical concrete construction, 88 ft in diameter and approximately 27 ft high.

The silos were designed to load with metal oxides in slurry form at a maximum rate of 8,000 gal per day. The radioactive residues were allowed to settle and the water was decanted, leaving sludge with a density of 100 lb/ft^3. The maximum allowable height of solid material was 23 ft and the water level was limited to a maximum height of 25 ft.

In 1963, berms were constructed around each silo to provide lateral support to the silo walls and, as a secondary benefit, to provide shielding. In 1990, a protective coating was applied to the silos to minimize concrete deterioration and reduce radon emissions. ^{222}Rn (3.8 day half-life, and 5.5 day mean-life) is generated at a rate in secular equilibrium with its ^{226}Ra parent. The nature of radon, being an inert radioactive gas, results in the continual release of the radionuclide from K-65 residues into the headspace of the silos. The actual quantity of radon present in the silo headspace is determined by the production rate (secular equilibrium) and the loss rate. There are essentially two loss mechanisms: the natural decay of radon gas and the escape of the gas from cracks and openings in the silo structure. After a period of time, there is a steady-state quantity of radon in the headspace. A Radon Treatment System (RTS) was added in 1987 to reduce the level of radon gas in the headspace above the residues. This system was operated only when access to the silo domes for sampling or maintenance was required.

Radon treatment involving a carbon collection system similar to the existing RTS results in a highly concentrated radon inventory with the carbon and a significant external radiation hazard. A person in proximity to the collection system without adequate controls would receive radiation exposures above allowable limits in a short period. Maintenance activities involving system entry must consider worker exposure to gamma radiation and radon and its immediate daughter products.

The K-65 silo area represented one of the most prevalent sources of gamma exposure at the FEMP. Past projects involving significant stay times in the proximity of K-65 have produced some of the larger personnel whole-body exposures at the FEMP since 1990.

From 1953 through 1955, the FEMP refinery processed pitchblende ore from the Belgian Congo. No chemical separation or purification had been performed prior to the receipt of the ore at the FEMP. The generated residues were not mixed with other site wastes but were placed in two dedicated silos. Pitchblende residues were first added to the concrete storage silos in 1953. The residues were batch-pumped from the FEMP refinery to the silos as aqueous slurry. The supernatant liquid was withdrawn and pumped back to the refinery to be used in the slurrying step. Additions to the silo ended in 1955 when the last pitchblende was processed at the FEMP. Also in 1955, pitchblende residues from another site were added to the silos. Core sampling of silo contents in 1972 showed a dry free-flowing powder at the surface and 40% moisture in the samples from the bottom.

A radiochemical analysis of the material in each silo material was performed in the past. Core sampling was performed on both silos and isotopic analyses reported for uranium, thorium, radium, and other radionuclides. Using the upper 95% confidence interval of the mean value, Tables 2-23 and 2-24 list the activity per gram of each radionuclide in Silos 1 and 2, respectively. The uranium appears to be 1% enriched, based on the relative activity of ^{238}U and ^{234}U to the total activity.

Table 2-23. Isotopic composition of K-65 Silo 1 (on a per gram of waste basis).

Isotope	Specific Activity (nCi/gm)	Activity fraction
Uranium (total)	1.68	1.61 E-3
Ac-227	7.67	17.36E-3
Pb-210	202	1.94E-1
Po-210	281	2.70E-1
Ra-226	477	4.58 E –1
Th-228	2.28	2.19 E-3
Th-230	68.9	6.62 E –2
Th-232	1.11	1.07 E -3

Table 2-24. Isotopic composition of K-65 Silo 2 (on a per gram of waste basis).

Isotope	Specific Activity (nCi/gm)	Activity fraction
Uranium (total)	2.37	3.04 E-3
Ac-227	6.64	8.50E-3
Pa-231	4.04	5.17 E -3
Pb-210	190	2.43 E-1
Po-210	231	2.96 E-1
Ra-226	263	3.36 E -1
Th-228	7.36	9.42 E-3
Th-230	76.2	9.75 E -2
Th-232	0.99	1.26 E -3

External dose characteristics of the silos depend on the radon and radon daughter activity in the silo headspaces that emit gamma radiation. The actual quantity of radon present in the silo headspace is determined by the production rate (secular equilibrium) and the loss rate. After a period of time, there is a steady-state quantity of radon and radon daughters in the silo headspace. The Preliminary Hazard Analysis Report for OU4 Silos (FEMP 1998) used 10 curies (each silo) for the release calculation and projected a releasable radon inventory per silo headspace after clay covering dried and cracked may exceed 30 curies per silo. FEMP (1998) stated that the general area exposure rate at either silo dome is about 25 mrem/hr.

Radon treatment involving a carbon collection system will result in a highly concentrated radon inventory in the carbon and a significant external radiation hazard. Maintenance activities involving system entry must consider worker exposures to gamma radiation, radon, its immediate decay daughters, and ^{210}Pb, which builds up with system operation.

Silo 3

Silo 3 contains approximately 138,000 cu ft of waste residues, known as cold metal oxides, which were generated during extraction operations in the 1950s involving uranium concentrates. The concentrates were received from a variety of uranium mills in the United Stated and abroad. The residues in Silo 3 are substantially different from those in Silos 1 and 2. First, Silo 3 residues are dry (~10% moisture) while K-65 material is wet (~30% moisture). The material was calcined prior to placement in Silo 3 and is now a fully oxidized fine powder. Second, while the radiological constituents are similar to those in Silos 1 and 2, some radionuclides such as radium are present in much lower concentrations. The major fraction of metal impurities, including radium, has been removed by the uranium mills prior to transfer to the FEMP site. Without the radium contribution, Silo 3 exhibits a much lower direct radiation field and radon emanation rate than those of Silos 1and 2.

The immediate concern involving Silo 3 is the risk of inhalation dose from suspended material following a release. The radionuclide having both the largest specific activity (60 nCi/gm) and the greatest fraction of relative dose (83%) in Silo 3 is Th-230, which is produced from the natural decay of ^{238}U.

The isotopic composition of Silo 3 can be derived from a past radiochemical analysis of the silo material. Table 2-25 lists the activity per gram of waste of each radionuclide in Silo 3. The uranium appears to be natural, based on the relative activity of ^{238}U and ^{234}U to the total activity.

Table 2-25. Isotopic composition of K-65 Silo 3 (on a per gram of waste basis).

Isotope	Specific Activity (nCi/gm)	Activity fraction
Uranium (total)	3.63	4.83 E-2
Ac-227	0.93	1.23 E-2
Pa-231	0.63	8.35 E-3
Pb-210	3.48	4.63 E-2
Ra-224	0.37	4.89 E-3
Ra-226	3.87	5.15 E-2
Ra-228	0.41	5.42 E-3
Th-228	0.75	9.95 E-3
Th-230	60.2	8.02 E-1
Th-232	0.84	1.12 E-2

The external dose characteristics for Silo 3 are based on the radium content. While the material stored in Silo 3 is similar to that on Silos 1 and 2, much of the radium had been removed by uranium mills prior to transfer to the FEMP site, and is present in much lower concentrations than in Silos 1 and 2. Without the radium contribution, Silo 3 exhibits a much lower direct radiation field and radon emanation rate than Silos 1 and 2. The primary hazard for workers is the inhalation of the fine powder in the silo.

Silo 4
As with Silo 3, Silo 4 was designed to receive cold metal oxides from uranium processing. Due to a process change in 1957, storage of the waste cold metal oxide was no longer necessary; Silo 4 was never used and is empty.

2.3.3.2 Low-Level Radioactive Waste Pit Area

The Waste Pit Area is west of the former production area and covers approximately 37.7 acres. It consists of Waste Pits 1, 2, 3, 4, 5, and 6 and the Burn Pit (also used for the disposal and burning of waste).

Waste Pit 1
Waste Pit 1 was constructed in 1952. Its surface area is oval-shaped with dimensions at the bottom of approximately 165 ft wide by 347 ft long. Its depth averages 29.5 ft, including approximately 18 ft of waste, 11 ft of lining, and a 6-in. cover. Waste Pit 1 is a dry pit, because waste slurries were filtered or calcined to remove water before they were placed in the pit. This pit primarily received neutralized waste filter cakes, vacuum-filtered sludges from production activities, magnesium fluoride slag, scrap graphite, and contaminated brick. Waste Pit 1 was closed and covered with clean fill in 1959. Waste inventory records indicate that Waste Pit 1 contains 1,075 metric tons of uranium. The radionuclide distribution for buried wastes in Waste Pit 1 are listed in Table 2-26.

Table 2-26. Waste Pit 1 isotopic content.

Radionuclides	Activity Concentration (pCi/gm of waste)		
	Avg	Min	Max
Cesium-137	0.43	0.2	1.1
Neptunium-237	--	--	--
Plutonium-238	--	--	--
Plutonium-239/240	--	--	--
Ruthenium-106	--	--	--
Strontium-90	--	--	--
Technetium-99	3.6	1	15
Thorium-228	20.14	6.1	52
Thorium-230	1,504.4	326	3,600
Thorium-232	21.62	7.7	55
Uranium-234	558.4	244	1180
Uranium-235	56	16	151
Uranium-238	1,950.6	360	6,980

The results of an airborne radon flux survey for Waste Pit 1 indicated an average radon flux of 9.1 $pCi/m^2/sec$ with a limited regional maximum radon-flux density of 75 $pCi/m^2/sec$ on the western boundary of the pit, next to the Clearwell. The observed radon flux pattern is probably an indication of localized areas that contain higher concentrations of ^{226}Ra, are more permeable, and allow the radon gas to escape more readily. Assuming an air velocity of 3.2 m/sec at the Waste Pit 1, the average radon-flux for Pit 1 in Working Level (WL) is 0.013 WL.

Airborne radioactive material concentration due to air particulate emissions at Waste Pit 1 for dose reconstruction purposes can be estimated using the fugitive uranium and thorium emissions from wind

erosion as estimated in the Addendum to FEMP-2082 (Appendix 2C). Table 2-27 presents the derivation and results.

Table 2-27. Airborne radionuclide concentration at Waste Pit 1 by years.

Year	A Exposed pit area m^2	B Uranium emission kg/yr	C Uranium flux[a] (B/A)×28.6 Bq/m^2-sec	D Uranium Concentration[b,c] Bq/m^3
1953	398.82	0.15	1.08E-02	3.36E-03
1954	638.04	0.25	1.12E-02	3.50E-03
1955	3,589.01	1.4	1.12E-02	3.49E-03
1956	5,184.10	2.0	1.10E-02	3.45E-03
1957	5,582.83	2.16	1.11E-02	3.46E-03
1958	5,582.83	2.16	1.11E-02	3.46E-03
1959	5,582.83	2.16	1.11E-02	3.46E-03
1960	5,582.83	2.16	1.11E-02	3.46E-03
1961	4,785.28	1.85	1.11E-02	3.46E-03
1962	3,987.73	1.54	1.10E-02	3.45E-03
1963	1,595.09	0.62	1.11E-02	3.47E-03
1964	797.55	0.31	1.11E-02	3.47E-03
1965	797.55	0.31	1.11E-02	3.47E-03
1966	797.55	0.31	1.11E-02	3.47E-03
1967	797.55	0.31	1.11E-02	3.47E-03
1968	1,196.37	0.46	1.10E-02	3.44E-03
1969	6,380.37	2.5	1.12E-02	3.50E-03
1970	5,582.83	2.15	1.10E-02	3.44E-03
1971	4,785.28	1.85	1.11E-02	3.46E-03
1972	3,987.73	1.54	1.10E-02	3.45E-03
1973	3,190.19	1.23	1.10E-02	3.45E-03
1974	2,392.64	0.92	1.10E-02	3.44E-03
1975	1,595.09	0.62	1.11E-02	3.47E-03
1976	797.55	0.31	1.11E-02	3.47E-03

[a] Based on 2% enriched uranium.
[b] Assumed an air velocity of 3.2 m/sec at Waste Pit 1.
[c] Radionuclide (e.g., Pu, Np, Tc and U isotopes) radioactivity fractions for recycled uranium is given in Table 2-54

Direct radiation for Waste Pit 1 is within the beta/gamma dose rate contour of 1.0 mRad/hr. Radiological analyses for soil samples taken in these areas indicate that uranium is the principal constituent for the elevated dose rates.

Waste Pit 2

Waste Pit 2 was constructed northeast of Waste Pit 1 in 1957. The surface area boundary of Waste Pit 2 resembles a six-sided polygon with dimensions at the top of approximately 19 ft wide by 270 ft long. It is approximately 23.5 ft deep including 15 ft of lining and 1 to 4 ft of cover. Waste Pit 2 is a dry pit that received primarily waste filter cakes, vacuum-filtered production sludge, magnesium fluoride slag, scrap graphite, contaminated brick, and concentrated raffinate residues. It was closed and covered with clean fill in 1964. Waste inventory records indicate that Waste Pit 2 contains 175 MTU. The radionuclide distribution for buried wastes in Waste Pit 2 are listed in Table 2-28.

The results of an airborne radon flux survey for Waste Pit 2 indicated an average radon flux of 6.4 pCi/m^2/sec. The maximum radon flux measurement in Waste Pit 2 was 81.1 pCi/m^2/sec in the southwestern part of the pit. The raffinate waste from Plant 2/3 disposed of in this pit contains

elevated concentrations of ^{226}Ra that are the source of radon. The observed radon flux pattern probably reflects localized areas that contain higher concentrations of ^{226}Ra that are more permeable, and allow the radon to escape more readily. Assuming an air velocity of 3.2 m/sec at the Waste Pit 2, the average radon-flux for Pit 2 in Working Level (WL) is 0.014 WL.

Table 2-28. Waste Pit 2 isotopic content.

Radionuclides	Activity Concentration (pCi/gm of waste)		
	Avg	Min	Max
Cesium-137	1.15	0.2	3.6
Neptunium-237	--	--	--
Plutonium-238	0.1	0.07	0.1
Plutonium-239/240	0.16	0.05	0.6
Ruthenium-106	--	--	--
Strontium-90	--	--	--
Technetium-99	128.9	1	618
Thorium-228	62.6	11	164
Thorium-230	1,434.8	41	3,980
Thorium-232	42.6	11	88
Uranium-234	3,866.6	40	18,200
Uranium-235	1,793	2	8,780
Uranium-238	4,725.4	60	17,900

Tables 2-29 and 2-30 provide, respectively, the estimated airborne uranium and thorium particulate concentration due to the fugitive uranium and thorium emissions from wind erosion at Waste Pit 2.

Table 2-29. Airborne uranium concentration at Waste Pit 2 by years.

Year	A Exposed pit area m^2	B Uranium emission kg/yr	C Uranium flux[a] (B/A)×28.6 Bq/m^2-sec	D Uranium Concentration[b,c] Bq/m^3
1957	1,651.85	46.4	8.03E-01	2.51E-01
1958	3,303.71	92.7	8.02E-01	2.51E-01
1959	3,303.71	92.7	8.02E-01	2.51E-01
1960	3,716.74	104.3	8.03E-01	2.51E-01
1961	4,129.68	115.9	8.03E-01	2.51E-01
1962	4,129.68	115.9	8.03E-01	2.51E-01
1963	4,129.68	115.9	8.03E-01	2.51E-01
1964	4,129.68	115.9	8.03E-01	2.51E-01
1965	2,064.89	57.95	8.03E-01	2.51E-01
1966	1,238.91	34.8	8.03E-01	2.51E-01

[a] Based on 2% enriched uranium. [b] Assumed an air velocity of 3.2 m/sec at Waste Pit 2.
[c] Radionuclide (e.g., Pu, Np, Tc and U isotopes) radioactivity fractions for recycled uranium is given in Table 2-54.

Table 2-30. Airborne thorium concentration at Waste Pit 2 by years.

Year	A Exposed pit area m^2	B Thorium emission kg/yr	C Thorium flux (B/A)×1.29 Bq/m^2-sec	D Thorium Concentration[a] Bq/m^3
1957	1,651.85	0.014	1.08E-05	3.39E-06
1958	3,303.71	0.032	1.24E-05	3.87E-06
1959	3,303.71	0.032	1.24E-05	3.87E-06

Year	A Exposed pit area m^2	B Thorium emission kg/yr	C Thorium flux (B/A)×1.29 Bq/m^2-sec	D Thorium Concentration[a] Bq/m^3
1960	3,716.74	0.032	1.10E-05	3.44E-06
1961	4,129.68	0.036	1.12E-05	3.49E-06
1962	4,129.68	0.036	1.12E-05	3.49E-06
1963	4,129.68	0.036	1.12E-05	3.49E-06
1964	4,129.68	0.036	1.12E-05	3.49E-06
1965	2,064.89	0.018	1.12E-05	3.49E-06
1966	1,238.91	0.01	1.03E-05	3.23E-06

[a] Assumed an air velocity of 3.2 m/sec at Waste Pit 2.

Direct radiation for Waste Pit 2 is within the beta gamma dose rate contour of 1.2 mRad/hr. Radiological analyses for soil samples taken in these areas indicate that uranium is the principal constituent for the elevated dose rates.

Waste Pit 3

Waste Pit 3 was placed in service in December 1958. The surface area boundary of the pit is oval-shaped and has dimensions of approximately 450 ft wide by 720 ft long. This pit is approximately 42 ft deep, which includes a maximum of 14 ft of cover material, 27 ft of wastes, and an estimated 1 ft of native clay. Waste Pit 3 was the first waste pit built specifically for settling solids from liquid waste streams. Primarily lime-neutralized raffinate slurries and contaminated surface-water runoff were pumped to this pit. After Waste Pit 2 was filled, Waste Pit 3 received vacuum-filtered production sludge, neutralized liquid from process systems, neutralized refinery sludges, and cooling water from heat treatment operations. During the late 1960s, large quantities of neutralized residues from acid leaching of uranium-bearing magnesium fluoride slag were pumped to Waste Pit 3. In 1973, fill material (including filter cake, slag leach residue, lime sludge, and flyash) was placed in Waste Pit 3 and construction activities were initiated to cover this waste with soil. Covering activities were complete in 1977. Waste inventory records indicate that Waste Pit 3 contains 846 MTU. The radionuclide distribution for buried wastes in Waste Pit 3 are listed in Table 2-31.

Table 2-31. Waste Pit 3 isotopic content.

Radionuclides	Activity Concentration (pCi/gm of waste)		
	Avg	Min	Max
Cesium-137	--	--	--
Neptunium-237	0.53	0.2	2.1
Plutonium-238	0.23	0.08	1
Plutonium-239/240	2.13	0.05	14
Ruthenium-106	--	--	--
Strontium-90	1.31	0.6	5.2
Technetium-99	233.4	1.2	1,110
Thorium-228	11.79	1	40
Thorium-230	4,635.7	15	1,1680
Thorium-232	15.74	1	59
Uranium-234	207.71	27	475
Uranium-235	11.7	2.5	21
Uranium-238	442	134	1,380

The results of airborne radon flux survey for Waste Pit 3 indicated an average radon flux of 2.6 pCi/m^2/sec. The maximum radon-flux reading in Waste Pit 3 was 48 pCi/m^2/sec located on the south

part of the pit. The raffinate waste from Plant 2/3 disposed of in this pit contains elevated concentrations of ^{226}Ra that is the source of radon. The observed radon-flux pattern probably reflects localized areas that contain higher concentrations of ^{226}Ra, are more permeable, and allow the radon gas to escape more readily. Assuming an air velocity of 3.2 m/sec at the Waste Pit 2, the average radon-flux for Pit 2 in Working Level (WL) is 0.008 WL.

Table 2-32 provides the estimated airborne uranium particulate concentration and Table 2-33 provides the estimated airborne thorium concentration resulting from the fugitive uranium and thorium emissions from wind erosion at Waste Pit 3.

Table 2-32. Airborne uranium concentration at Waste Pit 3 by years.

Year	A Exposed pit area m^2	B Uranium emission kg/yr	C Uranium flux[a] (B/A)×28.6 Bq/m^2-sec	D Uranium Concentration[b,c] Bq/m^3
1962	4,127.64	0.63	4.37E-03	1.36E-03
1963	4,127.64	0.63	4.37E-03	1.36E-03
1964	22,014.14	3.36	4.37E-03	1.36E-03
1965	24,765.93	3.78	4.37E-03	1.36E-03
1966	24,765.93	3.78	4.37E-03	1.36E-03
1967	0.00	0.0	0.0	0.0
1968	0.00	0.0	0.0	0.0
1969	9,631.22	1.47	4.37E-03	1.36E-03
1970	16,510.65	2.52	4.37E-03	1.36E-03
1971	16,510.65	2.52	4.37E-03	1.36E-03
1972	8,255.28	1.26	4.37E-03	1.36E-03
1973	8,255.28	1.26	4.37E-03	1.36E-03
1974	2,751.79	0.42	4.37E-03	1.36E-03
1975	22,014.14	3.35	4.35E-03	1.36E-03
1976	22,014.14	3.35	4.35E-03	1.36E-03
1977	22,014.14	3.35	4.35E-03	1.36E-03
1978	19,262.44	2.94	4.37E-03	1.36E-03
1979	16,510.65	2.52	4.37E-03	1.36E-03
1980	12,383.01	1.89	4.37E-03	1.36E-03
1981	9,631.22	1.47	4.37E-03	1.36E-03
1982	4,127.64	0.63	4.37E-03	1.36E-03

[a] Based on 2% enriched uranium.

[b] Assumed an air velocity of 3.2 m/sec at Waste Pit 3.

[c] Radionuclide (e.g., Pu, Np, Tc and U isotopes) radioactivity fractions for recycled uranium is given in Table 2-54[c] Based on 2% enriched uranium

Table 2-33. Airborne thorium concentration at Waste Pit 3 by years.

Year	A Exposed pit area m^2	B Thorium emission kg/yr	C Thorium flux (B/A)×1.29 Bq/m^2-sec	D Thorium Concentration[a] Bq/m^3
1962	4,127.64	0.0	0.0	0.0
1963	4,127.64	0.0	0.0	0.0
1964	22,014.14	0.01	5.81E-07	1.82E-07
1965	24,765.93	0.014	7.24E-07	2.26E-07
1966	24,765.93	0.014	7.24E-07	2.26E-07
1967	0.00	0.0	0.0	0.0
1968	0.00	0.0	0.0	0.0

Year	A Exposed pit area m^2	B Thorium emission kg/yr	C Thorium flux (B/A)×1.29 Bq/m^2-sec	D Thorium Concentration[a] Bq/m^3
1969	9,631.22	0.005	6.65E-07	2.08E-07
1970	16,510.65	0.01	7.75E-07	2.42E-07
1971	16,510.65	0.01	7.75E-07	2.42E-07
1972	8,255.28	0.005	7.75E-07	2.42E-07
1973	8,255.28	0.005	7.75E-07	2.42E-07
1974	2,751.79	0.0	0.0	0.0
1975	22,014.14	0.01	5.81E-07	1.82E-07
1976	22,014.14	0.01	5.81E-07	1.82E-07
1977	22,014.14	0.01	5.81E-07	1.82E-07
1978	19,262.44	0.01	6.65E-07	2.08E-07
1979	16,510.65	0.01	7.75E-07	2.42E-07
1980	12,383.01	0.005	5.17E-07	1.62E-07
1981	9,631.22	0.005	6.65E-07	2.08E-07
1982	4,127.64	0.0	0.0	0.0

[a] Assumed an air velocity of 3.2 m/sec at Waste Pit 3.

Direct radiation in the form of beta/gamma dose rates range geometrically from 1.2 mRad/hr to 2.7 toward the middle of the pit. A high dose rate of 8.5 mRad/hr was measured at the northeastern boundary of the pit and a maximum beta gamma dose rate of 9.5 mRad/hr was measured in the northeast end of the pit. Radiological analyses for soil samples taken in these areas indicate that uranium is the principal constituent responsible for elevated dose rates.

Waste Pit 4

Waste Pit 4 was constructed in 1960. The surface area boundary of the waste pit is trapezoidal in shape and has maximum dimensions of approximately 380 ft wide by 310 ft long. The pit is approximately 32 ft deep, including 25 ft of waste, 1 to 2 ft of liner, and 6 ft of cover. It received solid wastes that included process residues, scrap uranium metal, off-specification intermediate uranium products and residues, thorium metal and residues, and contaminated ceramics. Process residues included filter sludges, raffinates, graphite, magnesium fluoride slag, and pyrophoric uranium-bearing materials. Thorium metal and residues were placed in Waste Pit 4 when additional metal recovery was not economically feasible. Waste Pit 4 disposal activities were terminated in 1985. The pit was closed in 1986 and cover activities were started. Waste inventory records indicate that Waste Pit 4 contains 2,203 MT of uranium and 74 MT of thorium. The radionuclide distribution for buried wastes in Waste Pit 4 are listed in Table 2-34.

The airborne radon flux measurements for Waste Pit 4 were considerably less than those for Pits 1, 2 or 3. All samples indicated an average radon flux of < 0.1 pCi/m^2/sec or < 3.13E-05 WL, in term of concentration.

Tables 2-35 and 2-36 provide, respectively, the estimated airborne uranium and thorium particulate concentration due to the fugitive uranium and thorium emissions from wind erosion at Waste Pit 4.

Table 2-34. Waste Pit 4 isotopic content.

Radionuclides	Activity Concentration (pCi/gm of waste)		
	Avg	Min	Max
Cesium-137	--	--	--
Neptunium-237	0.18	0.1	0.4
Plutonium-238	0.25	0.1	0.5

Radionuclides	Activity Concentration (pCi/gm of waste)		
	Avg	Min	Max
Plutonium-239/240	0.15	0.1	0.4
Strontium-90	--	--	--
Technetium-99	80.45	6.8	225
Thorium-228	114.75	18	395
Thorium-230	428.25	225	566
Thorium-232	37	17	92
Uranium-234	783.25	149	2,320
Uranium-235	152.25	35	426
Uranium-238	4,644	509	15,800

Table 2-35. Airborne uranium concentration at Waste Pit 4 by years.

Year	A Exposed pit area m^2	B Uranium emission kg/yr	C Uranium flux[a] (B/A)×28.6 Bq/m^2-sec	D Uranium Concentration[b,c] Bq/m^3
1960	890.26	1.9	6.10E-02	1.91E-02
1961	1,780.52	3.79	6.09E-02	1.90E-02
1962	3,561.14	7.58	6.09E-02	1.90E-02
1963	4,006.22	8.52	6.08E-02	1.90E-02
1964	4,451.40	9.47	6.08E-02	1.90E-02
1965	4,451.40	9.47	6.08E-02	1.90E-02
1966	4,896.57	10.42	6.09E-02	1.90E-02
1967	4,896.57	10.42	6.09E-02	1.90E-02
1968	5,341.66	11.36	6.08E-02	1.90E-02
1969	5,341.66	11.36	6.08E-02	1.90E-02
1970	5,341.66	11.36	6.08E-02	1.90E-02
1971	5,341.66	11.36	6.08E-02	1.90E-02
1972	5,786.83	12.3	6.08E-02	1.90E-02
1973	5,786.83	12.3	6.08E-02	1.90E-02
1974	5,786.83	12.3	6.08E-02	1.90E-02
1975	6,231.92	13.26	6.09E-02	1.90E-02
1976	6,677.09	14.2	6.08E-02	1.90E-02
1977	7,567.36	16.1	6.08E-02	1.90E-02
1978	8,457.62	18.0	6.09E-02	1.90E-02
1979	8,902.79	18.94	6.08E-02	1.90E-02
1980	8,902.79	18.94	6.08E-02	1.90E-02
1981	8,902.79	18.94	6.08E-02	1.90E-02
1982	8,902.79	18.94	6.08E-02	1.90E-02
1983	8,902.79	18.94	6.08E-02	1.90E-02
1984	8,902.79	18.94	6.08E-02	1.90E-02
1985	8,902.79	18.94	6.08E-02	1.90E-02
1986	8,902.79	18.94	6.08E-02	1.90E-02
1987	8,902.79	18.94	6.08E-02	1.90E-02
1988	8,902.79	18.94	6.08E-02	1.90E-02

[a] Based on 2% enriched uranium.

[b] Assumed an air velocity of 3.2 m/sec at Waste Pit 4.

[c] Radionuclide (e.g., Pu, Np, Tc and U isotopes) radioactivity fractions for recycled uranium is given in Table 2-54

Table 2-36. Airborne thorium concentration at Waste Pit 4 by years.

Year	A Exposed pit area m^2	B Thorium emission kg/yr	C Thorium flux (B/A)×28.6 Bq/m^2-sec	D Thorium Concentration[a] Bq/m^3
1960	890.26	0.38	5.46E-04	1.71E-04
1961	1,780.52	0.76	5.46E-04	1.71E-04
1962	3,561.14	1.53	5.50E-04	1.72E-04
1963	4,006.22	1.72	5.50E-04	1.72E-04
1964	4,451.40	1.91	5.49E-04	1.72E-04
1965	4,451.40	1.91	5.49E-04	1.72E-04
1966	4,896.57	2.1	5.49E-04	1.72E-04
1967	4,896.57	2.1	5.49E-04	1.72E-04
1968	5,341.66	2.3	5.51E-04	1.72E-04
1969	5,341.66	2.3	5.51E-04	1.72E-04
1970	5,341.66	2.3	5.51E-04	1.72E-04
1971	5,341.66	2.3	5.51E-04	1.72E-04
1972	5,786.83	2.49	5.51E-04	1.72E-04
1973	5,786.83	2.49	5.51E-04	1.72E-04
1974	5,786.83	2.49	5.51E-04	1.72E-04
1975	6,231.92	2.68	5.50E-04	1.72E-04
1976	6,677.09	2.87	5.50E-04	1.72E-04
1977	7,567.36	3.25	5.50E-04	1.72E-04
1978	8,457.62	3.64	5.51E-04	1.72E-04
1979	8,902.79	3.83	5.51E-04	1.72E-04
1980	8,902.79	3.83	5.51E-04	1.72E-04
1981	8,902.79	3.83	5.51E-04	1.72E-04
1982	8,902.79	3.83	5.51E-04	1.72E-04
1983	8,902.79	3.83	5.51E-04	1.72E-04
1984	8,902.79	3.83	5.51E-04	1.72E-04
1985	8,902.79	3.83	5.51E-04	1.72E-04
1986	8,902.79	3.83	5.51E-04	1.72E-04
1987	8,902.79	3.83	5.51E-04	1.72E-04
1988	8,902.79	3.83	5.51E-04	1.72E-04

[a] Assumed an air velocity of 3.2 m/sec at Waste Pit 4.

Direct radiation for Waste Pit 4 is within the beta/gamma dose rate contour of 1.3 mRad/hr. A maximum beta/gamma dose rate reading of 11 mRad/hr occurred in the southeast corner of the pit. An area between the southeast corner of Waste Pit 4 and the south corner of Waste Pit 6 exhibit a relatively high dose rate of 35 mRad/hr. Radiological analyses for soil samples taken in these areas indicate that uranium is the principal constituent causing elevated dose rates.

Waste Pit 5

Waste Pit 5 was placed into service in 1968. The pit surface area boundary is rectangular in shape and is approximately 820 ft long by 240 ft wide. The waste pit is approximately 29 ft deep, including 28 to 29 ft of wastes, with a membrane liner. Waste Pit 5 was a settling basin for slurries including neutralized raffinates, slurries from the acid leaching of uranium-bearing slags, and sump slurries that were generally filtered to remove solids. Supernatant and sludges, produced by the coprecipitation of thorium wastes with barium carbonate and aluminum sulfate and the precipitation uranium with calcium oxide, were disposed of in Waste Pit 5. The discharge of slurried waste materials into the pit ended in 1983, and use of this pit as a settling basin ended in 1987. Waste inventory records indicate that Waste Pit 5 contains 527 MT of uranium and 72 MT of thorium. The radionuclide distribution for buried wastes in Waste Pit 5 are listed in Table 2-37.

Table 2-37. Waste Pit 5 isotopic content.

Radionuclides	Activity Concentration (pCi/gm of waste)		
	Avg	Min	Max
Cesium-137	24.42	2	76
Neptunium-237	8.61	0.3	19
Plutonium-238	1.99	0.1	4.4
Plutonium-239/240	5.03	0.1	13
Ruthenium-106	--	--	--
Strontium-90	9.95	1.4	31
Technetium-99	1,274.5	423	2,990
Thorium-228	31.13	3.8	44
Thorium-230	4,475	330	8,480
Thorium-232	30.47	3.8	55
Uranium-234	638.33	310	1,250
Uranium-235	34.33	14	79
Uranium-238	641.17	387	1,230

The airborne radon flux density for Waste Pit 5 is assumed to be less than 0.1 pCi/m^2/sec or 3.13E-05 WL.

Tables 2-38 and 2-39 provide the estimated airborne uranium and thorium particulate concentration due to the fugitive uranium and thorium emissions from wind erosion at Waste Pit 5,respectively.

Table 2-38. Airborne uranium concentration at Waste Pit 5 by years.

Year	A Exposed pit area m^2	B Uranium emission kg/yr	C Uranium flux[a] (B/A)×28.6 Bq/m^2-sec	D Uranium Concentration[b,c] Bq/m^3
1974	1,659.19	0.28	4.83E-03	1.51E-03
1975	4,147.89	0.71	4.90E-03	1.53E-03
1976	13,273.27	2.27	4.89E-03	1.53E-03
1977	4,977.49	0.85	4.88E-03	1.53E-03
1978	4,977.49	0.85	4.88E-03	1.53E-03
1979	4,977.49	0.85	4.88E-03	1.53E-03
1980	4,977.49	0.85	4.88E-03	1.53E-03
1981	4,977.49	0.85	4.88E-03	1.53E-03
1982	4,977.49	0.85	4.88E-03	1.53E-03
1983	4,977.49	0.85	4.88E-03	1.53E-03
1984	4,977.49	0.85	4.88E-03	1.53E-03
1985	4,977.49	0.85	4.88E-03	1.53E-03
1986	4,977.49	0.85	4.88E-03	1.53E-03
1987	8,295.60	1.42	4.90E-03	1.53E-03
1988	11,066.62	1.9	4.91E-03	1.53E-03

[a] Based on 2% enriched uranium.
[b] Assumed an air velocity of 3.2 m/sec at Waste Pit 5.
[c] Radionuclide (e.g., Pu, Np, Tc and U isotopes) radioactivity fractions for recycled uranium is given in Table 2-54

Table 2-39. Airborne thorium concentration at Waste Pit 5 by years.

Year	A Exposed pit area m^2	B Thorium emission kg/yr	C Thorium flux (B/A)×28.6 Bq/m^2-sec	D Thorium Concentration[a] Bq/m^3
1974	1,659.19	0.1	7.71E-05	2.41E-05
1975	4,147.89	0.24	7.41E-05	2.31E-05
1976	13,273.27	0.76	7.33E-05	2.29E-05
1977	4,977.49	0.29	7.46E-05	2.33E-05
1978	4,977.49	0.29	7.46E-05	2.33E-05
1979	4,977.49	0.29	7.46E-05	2.33E-05
1980	4,977.49	0.29	7.46E-05	2.33E-05
1981	4,977.49	0.29	7.46E-05	2.33E-05
1982	4,977.49	0.29	7.46E-05	2.33E-05
1983	4,977.49	0.29	7.46E-05	2.33E-05
1984	4,977.49	0.29	7.46E-05	2.33E-05
1985	4,977.49	0.29	7.46E-05	2.33E-05
1986	4,977.49	0.29	7.46E-05	2.33E-05
1987	8,295.60	0.48	7.41E-05	2.31E-05
1988	11,066.62	0.64	7.40E-05	2.31E-05

[a] Assumed an air velocity of 3.2 m/sec at Waste Pit 5.

For dose reconstruction purposes, a beta/gamma direct radiation dose rate of less than 1 mRad/hr can be assumed for Waste Pit 5.

Waste Pit 6

Waste Pit 6 was completed in 1979. It is square in shape with sides measuring approximately 210 ft. It is approximately 24 ft deep, measured from the top of the berm to the liner, but the depth of the wastes in the pit is only 20 ft. Waste Pit 6 received only noncoarse nonpyrophoric materials (this excludes uranium and thorium in metallic form), including magnesium fluoride slag, process residues, and filter cakes from vacuum filtering operations to protect the membrane liner. In addition, extrusion residue and heat treatment quench water were deposited in Waste Pit 6. Use of the pit ended in 1985. Waste Pit 6 is currently covered by water. Waste inventory records indicate that Waste Pit 6 contains 1,432 MT of uranium. The radionuclide distribution for buried wastes in Waste Pit 6 are listed in Table 2-40.

Table 2-40. Waste Pit 6 isotopic content.

Radionuclides	Activity Concentration (pCi/gm of waste)		
	Avg	Min	Max
Cesium-137	17	4	31
Neptunium-237	2.03	0.9	3.6
Plutonium-238	0.78	0.4	1.4
Plutonium-239/240	8.7	4	15
Ruthenium-106	--	--	--
Strontium-90	4.1	2.6	5.1
Technetium-99	127	84	164
Thorium-228	0.5	0.2	1.2
Thorium-230	31	14	44
Thorium-232	0.5	0.2	1.2
Uranium-234	3,417.5	2,000	5,330
Uranium-235	1,042.5	350	1,750
Uranium-238	16,975	12,500	18,700

The airborne radon flux density for Waste Pit 6 is assumed to be less than 0.1 pCi/m^2/sec or 3.13E-05 WL, for dose reconstruction purposes.

Table 2-41 provides the estimated airborne uranium particulate concentration due to the fugitive uranium emissions from wind erosion at Waste Pit 6.

Table 2-41. Airborne uranium concentration at Waste Pit 6 by years.

Year	A Exposed pit area m^2	B Uranium emission kg/yr	C Uranium flux[a] (B/A)×28.6 Bq/m^2-sec	D Uranium Concentration[b,c] Bq/m^3
1979	301.00	8.26	7.85E-01	2.45E-01
1980	451.49	12.4	7.85E-01	2.45E-01
1981	752.49	20.7	7.87E-01	2.46E-01
1982	752.49	20.7	7.87E-01	2.46E-01
1983	752.49	20.7	7.87E-01	2.46E-01
1984	752.49	20.7	7.87E-01	2.46E-01
1985	752.49	20.7	7.87E-01	2.46E-01
1986	752.49	20.7	7.87E-01	2.46E-01
1987	752.49	20.7	7.87E-01	2.46E-01
1988	752.49	20.7	7.87E-01	2.46E-01

[a] Based on 2% enriched uranium.
[b] Assumed an air velocity of 3.2 m/sec at Waste Pit 6.
[c] Radionuclide (e.g., Pu, Np, Tc and U isotopes) radioactivity fractions for recycled uranium is given in Table 2-54

Waste Pit 6 is within the beta/gamma direct radiation dose rate contour of 1.3 mRad/hr. The highest dose rate, 35 mRad/hr, was identified near the southwest perimeter of Waste Pit 6.

Clearwell
The Clearwell was constructed in 1959 during Waste Pit 3 construction activities. It is approximately 200 ft long by 180 ft wide, with a maximum depth of 27 ft. It was a final settling basin for surface-water runoff from the waste pits and supernatant from Waste Pits 3 and 5. The Clearwell was dredged in the late 1960s or early 1970s, but has never been emptied or dredged again. Measurements indicate the presence of approximately 11 ft of sludge in the bottom of the Clearwell.

The radionuclide distribution in the Clearwell are listed in Table 2-42.

The airborne radon flux density for the Clearwell is assumed to be less than 0.1 pCi/m^2/sec or 3.13E-05 WL for dose reconstruction purposes.

The Clearwell is within the beta/gamma direct radiation dose rate contour of 1 mRad/hr.

Burn Pit
The Burn Pit is roughly between Waste Pits 2 and 4; it was initially excavated in 1957 to provide clay for lining Pits 1 and 2. Subsequently, combustible materials, including pyrophoric and reactive chemicals, oils, and other low-level contaminated combustible materials were burned in this pit. In addition, laboratory chemicals were disposed of at this site. Backfilling of the Burn Pit occurred prior to 1984. In 1984, all of the contents of the burn pit were transferred to Waste Pit 4.

The radionuclide isotopic content and isotopic distribution for buried wastes in Burn Pit are listed in Table 2-43.

Table 2-42. Clearwell isotopic content.

Radionuclices	Activity Concentration (pCi/gm of waste)		
	Avg	Min	Max
Cesium-137	189.5	18	450
Neptunium-237	1.04	0.3	2.2
Plutonium-238	--	--	--
Plutonium-239/240	--	--	--
Ruthenium-106	--	--	--
Strontium-90	8.48	1.3	26
Technetium-99	98.85	0.4	278
Thorium-228	36.75	20	56
Thorium-230	1,678.3	105	5,600
Thorium-232	19.2	2.8	39
Uranium-234	289.75	242	376
Uranium-235	35	24	49
Uranium-238	621.5	548	670

Table 2-43. Burn Pit isotopic content.

Radionuclides	Activity Concentration (pCi/gm of waste)		
	Avg	Min	Max
Cesium-137	--	--	--
Neptunium-237	0.27	0.1	0.6
Plutonium-238	0.13	0.1	0.5
Plutonium-239/240	0.11	0.1	0.4
Ruthenium-106	--	--	--
Strontium-90	--	--	--
Technetium-99	29.21	1.2	64
Thorium-228	7.63	1.5	19
Thorium-230	60.28	5.7	218
Thorium-232	7.18	1.1	21
Uranium-234	135.15	9.9	415
Uranium-235	8.37	0.5	27
Uranium-238	175.33	22	454

The airborne radon flux density for the Burn Pit is assumed to be less than 0.1 pCi/m^2/sec, or in term of concentration, 3.13E-05 WL for dose reconstruction purposes.

The Burn Pit is within the beta/gamma direct radiation dose rate contour of 1.3 mRad/hr.

Underground Storage Tanks

There are 11 underground storage tanks on the FEMP. At present, Tank 8 is the only tank in use that contains a hazardous substance (soluble oil machine coolant). Tank 6 contains waste oil, but it is no longer in use.

Sanitary Landfill

The FEMP sanitary landfill is on a 3-acre tract in the northwest corner of the production area. The facility has 17 individual cells, five of which are full and out of service. The 12 remaining cells are awaiting issuance of an Ohio Environmental Protection Agency (OEPA) permit to install. Each cell is

estimated to provide approximately 2,000 cubic yards (cy) of gross disposal volume. Materials accepted at the facility include: nonburnable, nonradioactive sanitary wastes generated on the site (20 cy/wk); nonradioactive construction-related rubble (variable quantity); and water treatment lime sludge (7 cy/wk).

2.4 FEMP REMEDIATION AND ENVIRONMENTAL RESTORATION ACTIVITIES SINCE 1989

The site production mission has been terminated and the site has been undergoing remediation and cleanup since 1989. The production level during the first half of 1989 was greatly reduced as compared to earlier years, and operations consisted mostly of processing waste residues. When production was suspended on July 10, most government production programs which used FEMP products were advised to find private-sector suppliers. The FEMP remains in standby for some segments of production until the government is confident commercial suppliers can meet future demand for uranium metal. Operations during the second half of 1989 were limited to containing and treating site effluents and packaging and shipping radioactive wastes for offsite disposal. Table 2-44 provides an abbreviated history timeline and further presents a summary of the remediation activities at FEMP by the years since 1990.

Table 2-44. Abbreviated history timeline and remediation and environmental restoration activities since 1990.

Year	Activities
Abbreviated Timeline	
1951	Construction of the Feed Materials Production Center began.
1952	Uranium production began (through 1989).
1986	EPA and DOE signed the Federal Facilities Compliance Agreement which initiated the remedial investigation/feasibility study process.
1989	Uranium production was suspended. The Fernald site was placed on the National Priorities List, which is the list of CERLA sites most in need of cleanup.
1991	Uranium production formally ended. The site mission changed from uranium production to environmental remediation and site restoration. As part of the Amended Consent Agreement, the site was divided into operable units for characterization and remedy determination.
1993	Environmental remediation activities were initiated at the FEMP.
1994	Environmental remediation activities under each of the operable unit's records of decision were initiated.
1996	All five operable units had signed records of decision, signifying the end of the 10-year remedial investigation/feasibility study process.
1997	Environmental remediation activities continued at the FEMP, including construction of Cell 1 of the on-site disposal facility with the first waste placement beginning in December. Remedy for Silos 1 and 2 was separated from the remedy for Silo 3.
1998	Decontamination of nuclear buildings and facilities (safe shutdown) neared completion, full-scale aquifer restoration was implemented, excavated soil volumes exceeded expectations, and cell construction at the on-site disposal facility continued.
1999	Excavation of the waste pits was initiated and 89,627 tons of waste was transported to Envirocare of Utah, Inc. Safe shutdown was completed ahead of schedule and 20 site structures were dismantled. Over 2 billion gallons of water were processed and 280,000 cubic yards of contaminated soil were excavated. The remedy for Silo 3 was selected.

Year	Activities
2000	The Record of Decision Amendment for Operable Unit 4 Silos 1 and 2 Remedial Actions was signed by EPA in July. On-site disposal facility Cell 1 was filled to capacity. Southern waste units' excavation was completed to design grade.
2001	On-site disposal facility Cell 1 was capped. Remediation of the southern waste units was completed.
2002	The Silos 1 and 2 Radon Control System began operations and successfully reduced radon levels within the silos. The off-site transfer of nuclear product material was completed. The on-site disposal facility conducted waste placement into Cells 2, 3, 4, and 5.
Remediation and Environmental Restoration Activities since 1990	
1990-1993	**Handling and Storing Radioactive and Hazardous Materials** Radioactive Materials • Pitchblende ore residues containing radium stored in the K-65 Silos, • Thorium and thorium compounds stored in several location within the production area, • Radioactive materials in the waste pits, • Uranium metal, • Uranium compounds, • Magnesium fluoride (MgF_2) contaminated with uranium, and • Scrap metal contaminated with uranium compounds. Hazardous Materials • Nitric acid, • Laboratory chemical, • Hydrochloric acid, • Sulfuric acid, • Methanol, and • Process waste. FEMP was refurbishing and adding buildings to store hazardous waste, repackaging some materials into new drums, and removing materials no longer needed since production has ended. For example, two new warehouses originally built to store uranium products had been converted to meet the requirements for hazardous waste storage. Also, thorium previously stored in a deteriorating above-ground silo, in bins, and in drums on an outdoor pad were repackaged in new drums and stored in a warehouse.
1995	UNH Neutralization Project (approximately 200,000 gallons of Uranyl Nitrate Hexahydrate (UNH) were neutralized and prepared for disposal). Vitrification Pilot Plant (construction continued) Thorium Nitrate Stabilization (almost 6,000 gals of thorium nitrate were treated and solidified.) Plant 4 Decontamination & Decomissioning (D&D)
1996	Thorium Overpacking Project (To overpack 5,600 deteriorated drums of thorium for safe transportation and permanent, off-site disposal). Vitrification Pilot Plant (construction complete, full scale remediation would use vitrification to convert residues from silos 1 and 2 into a glass form. Approximately 36 tons of glass were produced during Phase I vitrification).

Year	Activities
	Plant 4 Decontamination & Decommissioning (D&D) (The building was emptied, cleaned, and stripped down to its structural-steel frame work. Plant 1 Decontamination & Decommissioning (D&D) (continued decontamination and dismantling activities). Above-Grade Dismantlement of (Temporary) High and Low Nitrate Tanks Advance Wastewater Treatment (AWWT) Slurry Dewatering Facility Online Legacy Mixed Waste Shipped Off Site (shipment of 28,000 lbs of legacy mixed waste to Envirocare of Utah). FEMP Continued Shipments of Uranium Metal Inventory (approximately half of the FEMP's 32 million net pound inventory of uranium metal products had been removed). Liquid Waste Project (completed shipping legacy liquid mixed waste to the Toxic Substance Control Act (TSCA) incinerator, located in Oak Ridge.)
1997-2002	Waste Pits Remedial Action Project (This project is responsible for the completion of remediation activities for the excavation, drying, loading, and rail transport of content of Waste Pits 1-6, the burn pit and the clearwell to an off-site disposal facility). Soil Characterization and Excavation Project (This project is responsible for the completion of remediation activities to address contaminated soil at the FEMP and miscellaneous waste units. On-Site Disposal Facility Project (This project is responsible for the construction of an eight-cell engineered disposal facility, and operation and maintenance of a leachate collection system). Facilities Closure and Demolition Project (This project is responsible for the completion of decontamination and dismantling of the above-grade portion of the former uranium processing facilities and all remedial action facilities). Silos Project (This project is responsible for the completion of remediation activities for the contents of K-65 Silos 1 and 2 and Silo 3, including the removal stabilization, and transport of the inventoried residues for off-site disposal). Aquifer Restoration and Wastewater Project (This project is responsible for the completion of remediation activities necessary to restore the water quality in the affected portions of the Great Miami Aquifer).

2.5 FEMP RADIOACTIVE MATERIALS AND CHARACTERISTICS

The primary radiological materials at the FEMP are uranium and uranium compounds, recycle uranium, thorium and thorium compounds, and radon and thoron.

2.5.1 Uranium and Uranium Compounds

Since 1951, uranium metal production has been the primary activity at the FEMP. Because of this, uranium has been widely distributed throughout the site and comprises the most likely source of external beta exposure and internal exposure at the site. Uranium received at the FEMP usually has been through one or more chemical separations at other sites. The separations remove most of the daughter products. Significant in-growth of daughters from purified uranium is limited to beta-gamma emitters ^{234}Th and ^{234m}Pa, both of which are daughters of ^{238}U. Those isotopes reach equilibrium within a few months after refining and are insignificant for radiological dose considerations when compared to the uranium isotopes present.

High quality uranium compounds were introduced into the FEMP processes at several points. Impure starting materials were dissolved in nitric acid and the uranium was extracted into an organic liquid. The uranium was then back-extracted into dilute nitric acid to yield a solution of uranyl nitrate.

Evaporation and heating were used to convert the nitrate solution to uranium trioxide (UO_3) powder. This compound was reduced to uranium dioxide (UO_2) with hydrogen and then converted to uranium tetrafluoride (UF_4) by reaction with anhydrous hydrogen fluoride. Uranium metal was produced by reacting UF_4 and magnesium metal in a refractory-lined reduction vessel. The primary uranium metal was remelted with scrap uranium metal to yield a purified uranium ingot that was shipped off the site for extrusion.

Based on the discussion of past FEMP operations, there are a variety of compounds of uranium that have been used and are present at the FEMP. For example, UO_3 was the major refinery product at Plants 2/3, while the Plant 4 process started with UO_3 and ended with a UF_4 product. The production conducted in Plant 5 generated dusts of UF_4 and uranium oxides (in MgF_2). The principal uranium dust produced in the Plant 5 remelt area, Plant 9, and Plant 8 were uranium oxides that are generally considered to be U_3O_8. Various compounds were handled in Plant 1, Plant 8, and the Pilot Plant. Table 2-45 summarizes the uranium compounds in each plant.

During production, the FEMP processed uranium with enrichment levels that ranged from depleted to as high as 20%. In general, 2% enriched uranium was the highest enrichment that was processed in significant quantities. A history (1961-1984) of the average uranium enrichment in dust collector stack discharges indicated ^{235}U enrichment levels ranging from 0.2% to 1.68% with an average of 0.7%.

Table 2-45. Uranium compounds in former production areas.

Plant	Likely compounds
1	Mixed
2/3	Uranyl Nitrate, UO_3, U-oxides
8	Mixed
Pilot	Mixed
4	UO_3, UF_4
5	UF_4, U-oxides, U-metal
6	U-metal, U-oxides
9	U-metal, U-oxides

Much of the onsite uranium has been stored in drums. These drums contain what are called “uranium residues.” These residues have been assayed by the analytical laboratory. The analyses have provided detailed information on the percent uranium in the drums (as well as the percentage of

enrichment of the material in the drums) that closely matches that reported for dust collector stack discharges. Several of the drums contain enrichment levels of approximately 3%, but they represent very small quantities of uranium.

The specific activity of uranium increases with enrichment principally because of an increase in ^{234}U activity. In the gaseous diffusion process, ^{234}U is enriched to a greater extent than ^{235}U. This effect on ^{234}U enrichment must be considered when performing dose calculations for a particular degree of ^{235}U enrichment. Table 2-46 provides relative activity characteristics of depleted, natural, and 2% enriched uranium.

Table 2-46. Relative activity of uranium mixtures.

	nCi/mg of material			
Mixture	**U-234**	**U-235**	**U-238**	**Total**
Depleted	0.023	0.005	0.336	0.364
Natural	0.338	0.015	0.334	0.687
2% Enriched	0.801	0.043	0.329	1.174

In 1980, 89,000 lb of material identified as “Feed Plant Ash or Other Paducah Scrap” was shipped from the Paducah Gaseous Diffusion Plant to the FEMP. This material contained 22.5 metric tons of uranium and transuranic contamination that was 200 times higher than what was typical for recycled uranium. The material introduced plutonium, neptunium, and technetium to the process stream. The isotopic composition and related dosimetry of this material is discussed in the section on recycled uranium in this TBD.

A five-day field study was conducted by the Technical Safety Support Branch of EG&G Idaho, Inc. (Alvarez et al. 1984). The basic findings of this field study are presented in the following discussions.

The principal gamma emissions from depleted uranium included the 63- and 93-keV transitions that follow the beta decay of ^{234}Th, and the 765- and 1,001-keV transitions associated with the isomeric state of ^{234}Pa. Uranium X-rays are major contributors to the photon flux from depleted uranium. These X-rays arise from the removal of K and L electrons by both alpha and beta particles. Uranium X-ray emissions occur at 13.4, 13.6, 16.4, and 17.2 keV corresponding to the $U_L\alpha_2$, and ULα1, $U_L\beta_2$ and $U_L\beta_1$ transitions. The uranium K series of X-ray emission occurs at 94.6, 98.4, 101.3 and 114.5 keV, corresponding to the $U_K\alpha_2$, $U_K\alpha_1$, $U_K\beta_2$, and $U_K\beta_1$ transitions. Gamma emission at 185 keV accompanied by weaker lines at 143, 163, and 205 keV indicate the presence of ^{235}U.

The beta spectrum of processed uranium metal and compounds tends to be dominated by the hard beta spectrum of ^{234}Pa with an E_{max}=2.28 MeV (98%). The two betas from the decay of ^{234}Th with E_{max}=0.191 MeV (79%) can be important contributors to the shallow skin dose at close range because intermediate beta energies deposit more energy per beta particle in the critical tissue depth defining skin dose.

The source materials presently on the site are no different than those present when the 1984 study was performed. Therefore, the same exposure sources are present but in a shielded state due to packaging in preparation for shipping or storage. The major change in the energy spectrum found would be a decrease in average energies due to shielding from packaging materials.

2.5.2 Recycle Uranium

In 1985, a Department of Energy Task Force evaluated the processing of “recycle uranium” at several DOE facilities. *Recycle uranium* was defined as uranium that had been recovered from irradiated

production reactor fuel. Recycle uranium is known to contain traces of transuranic (TRU) and fission product impurities. TRU impurities were usually limited to ^{237}Np, ^{238}Pu, and ^{239}Pu, and the radioactivity of the TRU impurities was generally less than 0.1% of the total radioactivity of the recycle uranium. Recycle uranium also contains trace quantities of ^{241}Am and ^{99}Tc.

From an internal dosimetry perspective, the most significant recycle uranium on the site is that which has been dubbed "POOS" for plutonium-out-of-specification. POOS uranium is that in which the total alpha activity from TRU elements exceeds 0.1% of the alpha activity from the uranium. This equates approximately to 11 parts of plutonium per billion parts of uranium on a mass basis.

Since the specific activity of ^{239}Pu is 2.27 dps/nanogram, natural uranium containing one part per billion ^{239}Pu has a corresponding activity concentration of 61.4 pCi ^{239}Pu per gram of uranium. Therefore, uranium that exceeds the TRU specification of 11 ppb will have a ^{239}Pu activity concentration of 675 pCi ^{239}Pu per gram of uranium. Most POOS uranium at the FEMP contains less than 80 ppb ^{239}Pu, which corresponds to an activity concentration of 4,910 pCi ^{239}Pu per gram of uranium. A few containers at the FEMP have uranium residues containing TRU constituents significantly higher than 80 ppb.

2.5.3 Thorium and Thorium Compounds

Since 1972, the FEMP served as the thorium materials repository for DOE. Approximately two-thirds of the material in the repository was processed at FEMP. The remainder originated at other DOE facilities. Thorium was stored on the site in approximately 15,000 containers of various sizes. Many containers have been removed from the site during the remediation process. The remaining thorium (approximately 500,000 lbs) is stored in approximately 200 metal boxes. The thorium is primarily a mixture of thorium metal, thorium oxides, and process residues. The thorium metals, oxides, and residues are segregated and stored separately from uranium products. These storage areas have the highest gamma dose rates at the FEMP. Projects involving thorium material handling routinely have yielded the highest worker whole-body doses since 1990. Several operations involved the processing or handling of thorium. The major potential source of exposure to thorium material currently at the FEMP is the repacking and shipping of the remaining containers of thorium.

In addition to the stored thorium, a number of locations on the site contain significant quantities of Th-230. These sites includes the K-65 silos and the waste pits, and, to a lesser degree, various parts of Plant 2/3 and Plant 8. The ^{230}Th at these locations resulted from the processing of uranium ores. Once the uranium had been extracted from the ore, the remaining material, known as raffinate, contained elevated levels of uranium decay products.

The thorium metal stored on the site is primarily ^{232}Th. Because most of the material has been stored for some time, it can be assumed that it has a significant amount of daughter in-growth. The ^{228}Th daughter of ^{232}Th is an alpha-emitter nuclide with specific effective energy values comparable to those of the parent. For determining daughter isotope concentrations, the material is considered to be 35 years old.

The other thorium isotope of concern is ^{230}Th. As previously discussed, ^{230}Th is present as a residue from the processing of ore. Much of the ^{230}Th on the site is the result of processing pitchblende ore from the Belgian Congo.

2.5.4 Radon and Thoron

Past operations at the FEMP have resulted in enhanced radon and thoron levels. The site stores materials that are parent materials to both radon and thoron. At present, it stores approximately 8,800 metric tons of uranium residues produced during plant operations since the1950s. During the period of production, uranium was chemically separated from pitchblende ore, and the waste residue, which contains high concentrations of ^{226}Ra, the parent to radon, was stored in the K-65 silos. As ^{226}Ra decays, it produces ^{222}Rn, an inert gas, which can diffuse into the atmosphere through the silo cover. A sealant barrier of bentonite clay was applied to the contents of the silo in November 1991 to reduce radon emissions. As a result of past operations, certain areas of the site have been contaminated with ^{226}Ra-bearing materials. This has resulted in elevated radon gas concentrations at several locations in the former process area.

Rn-222, commonly referred to as thoron, is a radioactive gas resulting from the decay of ^{224}Ra, which is in the thorium decay chain. The thorium metal and residues stored on the site are primarily ^{232}Th. Because most of the material and residues have been stored for some time, there is a significant amount of ^{224}Ra present, which results in the generation of thoron gas.

Radon and thoron data have been collected in specific radium- and thorium-bearing areas on the FEMP site to determine areas that have elevated concentrations. Available data were provided above in the descriptions of production plants.

Rn-222 has a half-life of 3.82 days. The decay of radon gas results in the production of four short-lived solid decay products: ^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po. The decay products build up rapidly with time and can approach secular equilibrium with the radon gas. Table 2-47 lists the progeny, decay modes, energies, and half-lives. The extremely short half-life of ^{214}Po dictates that it is in equilibrium with ^{214}Bi. The effective half-life of the radon progeny is approximately 40 minutes. Therefore, it takes approximately 3 hours for the radon progeny to come into equilibrium with the radon gas in a closed system.

Table 2-47. Physical properties of radon and its progeny.

Element	Principle radiation	Decay energies	Half-life
Rn-222	α	5.5 MeV	3.82 days
Po-218	α	6.0	3.05 min.
Pb-214	B,γ	1.0 (max)	26.8 min
Bi-214	B,γ	3.3 (max)	19.7 min.
Po-214	α	7.7	164 µsec

In an open system, the progeny exist in atomic form for a period dependent on the availability of aerosol surfaces for attachment. The percent of radon progeny associated with airborne particulates is referred to as the attached fraction. The higher the concentration of ambient aerosols, the larger the attached fraction. The radioactive aerosol usually contains both attached and unattached progeny. Attached and unattached progeny are continually plating out onto floors, walls, etc., or being removed by filtration. As a result, radon progeny will not be in secular equilibrium. Typical ratios for activities of ^{222}Rn/^{218}Po/^{214}Pb/^{214}Bi (^{214}Po) are 1.0/0.5/0.3/0.2 for indoors and 1.0/0.9/0.7/0.7 for outdoors.

Thoron (^{220}Rn) has a half-life of 55.6 seconds. The decay of thoron gas produces four progeny: ^{216}Po, ^{212}Pb, ^{212}Bi, and ^{212}Po. Table 2-48 lists the progeny, decay modes, energies, and half-lives. For thoron and its progeny, there is a greater degree of disequilibrium when compared to radon and its progeny. The longer half-life of ^{212}Pb results in a greater opportunity for it to be lost from an air mass

by deposition on nearby surfaces. With the exception of the short-lived ^{216}Po, thoron progeny, like radon progeny, are primarily in the attached state. This results in a significant increase in equilibrium when there is an increase in aerosol concentrations. The equilibrium factor has been reported to range between 0.002 and 0.06. At the FEMP, equilibrium values have been documented to range between 0.02 and 0.10 at several locations.

Table 2-48. Physical properties of thoron and its progeny.

Element	Principle radiation	Decay energies	Half-life
Rn-220	α	6.3 MeV	55.6 sec.
Po-216	α	6.8	0.15 sec.
Pb-212	β,γ	0.6 (max)	10.64 hours
Bi-212	β,γ	2.2 (max)	60.6 min.
Po-212	α	8.8	0.3 μsec

2.5.5 Specific Activities and Conversion Factors

Table 2-49. contains specific activities and activity fractions for uranium, recycled uranium and thorium and conversion factor for radon concentration unit of Working Levels (WL).

Table 2-49. Conversion factors and isotopic and radionuclide activity fractions for recycled uranium

Specific Activities for Recycled Uranium:

Uranium Enrichmt	U+Cont. (Bq/mg)	U		Pu - 80ppb		Np – 300 ppb		Tc- 5000 ppb	
		Bq/mg	*f* act.	Bq/mg	*f* act.	Bq/mg	*f* act.	Bq/mg	*f* act.
Depleted	4.53E+01	1.38E+01	0.305	1.83E-01	0.004	7.77E-03	1.72E-04	3.13E+00	0.69
Natural	5.76E+01	2.61E+01	0.453	1.83E-01	0.003	7.77E-03	1.35E-04	3.13E+00	0.54
2% Enrich	9.14E+01	6.03E+01	0.66	1.83E-01	0.002	7.77E-03	8.50E-05	3.13E+00	0.34

Specific Activities for Enriched Uranium:

Uranium Enrichment	Isotopes	Mass %	*f* activities
Depleted	U-234	05	0.083
	U-235	0.25	0.014
	U-238	99.75	0.903
Natural	U-234	0.0057	0.504
	U-235	0.7204	0.023
	U-238	99.273	0.473
2% Enrich	U-234	0.02	0.770
	U-235	2.0	0.026
	U-238	97.98	0.204

Specific Activities for Thorium:

Thorium-232 would be the default isotope. The degree of equilibrium is impossible to estimate, due to the variation in times since chemical separation of the feed stock. The specific activity value for ^{232}Th and daughters is 1.11E-07 Ci/gm or 4.11Bq/mg.

Working Level (WL) Conversion Factor for Rn daughters:

1 WL = 100 pCi/L for 100% Rn daughter equilibrium
1 WLM (100% equilibrium) = 1.70E+04 pCi

$$\text{No. of } WLM = \frac{Equalibrium\ Faction \times Exposure\ Time}{1.0\ WLM_{100}} \times Rn\ Concentration, = \frac{f_{eq} \times 2000}{17000} \times Concentration \frac{pCi}{L},$$

WLM = 0.118 (f_{eq})(Rn concentration in pCi/L), equilibrium factor f_{eq} = 0.4(for indoor), 0.7(for outdoor) and 2,000 hrs exposure time.

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GLOSSARY

Atomic Energy Commission
Original agency established for nuclear weapons and power production; a predecessor to the U.S. Department of Energy.

beta radiation
Radiation consisting of charged particles of very small mass (i.e., the electron) emitted spontaneously from the nuclei of certain radioactive elements. Most (if not all) of the direct fission products emit beta radiation. Physically, the beta particle is identical to an electron moving at high velocity.

black oxide
Uranium oxide (U_3O_8) characterized by its olive green to black coloration.

brown oxide
Uranium dioxide (UO_2) characterized by its brown coloration.

curie
A special unit of activity. One curie exactly equals 3.7×10^{10} nuclear transitions per second.

exposure
As used in the technical sense, exposure refers to a measure expressed in roentgens (R) of the ionization produced by photon radiation (i.e., gamma and X rays) in air.

gamma rays (G or γ)
Electromagnetic radiation (photons) originating in atomic nuclei and accompanying many nuclear reactions (e.g., fission, radioactive decay, and neutron capture).

green salt
Uranium tetrafluoride (UF_4) characterized by its green coloration.

ionizing radiation
Electromagnetic or particulate radiation capable of producing charged particles through interactions with matter.

Jolter
The jolter is used to compact the magnesium fluoride slag lining in the metal reduction reactor pot by an up and down jolting action.

orange oxide
Uranium trioxide (UO_3) characterized by its orange coloration.

photon
A unit or "particle" of electromagnetic radiation consisting of x- and/or gamma rays.

Rad
The unit of absorbed dose**.**

radiation
Alpha, beta, neutron, and photon radiation.

radioactivity

The spontaneous emission of radiation, generally alpha or beta particles, gamma rays, and neutrons from unstable nuclei.

rem

The rem is a unit of dose equivalent, which is equal to the product of the number of rad absorbed and the "quality factor."

Roentgen (R or r)

A unit of exposure to gamma or X-ray radiation. It is defined precisely as the quantity of gamma or X-ray radiation that will produce a total charge of 2.58×10^{-4} coulomb in 1 kg of dry air STP. An exposure of 1 R is approximately equivalent to an absorbed dose of 1 rad in soft tissue for higher (~>100 keV) energy photons.

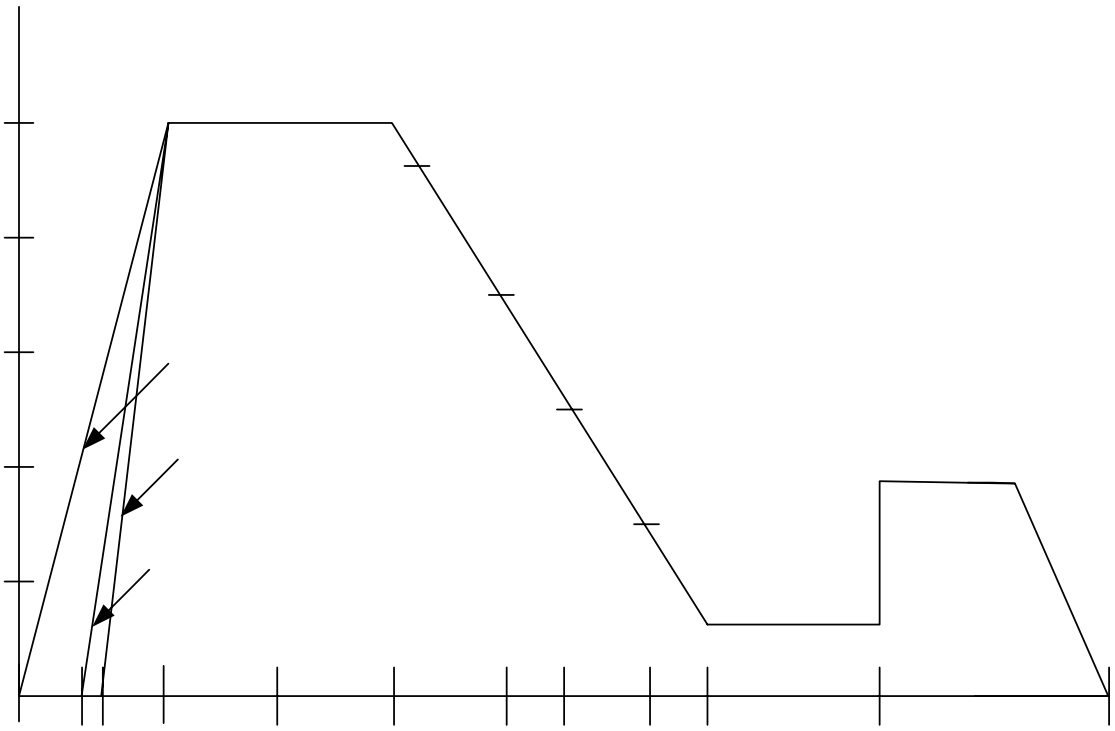
shielding

Any material or obstruction that absorbs (or attenuates) radiation and thus tends to protect personnel or materials from radiation.

smoking area

An area designated for cigarette smoking.

Appendix 2A. Default Model of FEMP Production Rate History for Dose Reconstruction Purposes.



10,000 M
100% sy

10,000

nium

8,000

Appendix 2B. FEMP uranium emissions summary by plant (kg).

Year	Plant 1	Plant 2/3	Plant 4	Plant 5	Plant 6	Plant 7	Plant 8	Plant 9	Pilot Plant	Lab	Oil & graphite burner	Solid & liquid waste incineration	N.A.R.	Cooling towers	Year total
1951	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	123.0	0.0	0.0	0.0	0.0	2.9	125.9
1952	0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	493.0	0.0	0.0	0.0	3.0	2.9	504.9
1953	3.8	6.0	1,473.0	90.0	14.1	0.0	0.0	0.0	493.0	1.9	0.0	0.0	3.0	2.9	2,087.7
1954	46.2	281.4	5,891.0	4,119.1	34.3	4,261.0	418.1	0.0	271.0	1.9	0.0	15	3.0	2.9	15,345.0
1955	46.2	1,115.1	12,452.0	10,410.4	65.3	7,268.0	1,825.4	0.0	443.0	1.9	0.0	118	3.0	2.9	33,751.2
1956	43.4	1,981.4	5,148.1	3,501.5	42.2	1,743.0	2,758.6	0.0	32.0	1.9	0.0	118	3.0	2.9	15,376.0
1957	49.4	3,735.4	819.7	3,664.8	51.8	0.0	2,366.7	0.4	18.0	1.9	0.0	118	3.0	2.9	10,814.0
1958	407.4	3,526.5	668.4	715.5	177.3	0.0	2,525.7	681.0	27.0	1.9	0.0	118	3.0	2.9	8,854.6
1959	46.0	3,936.4	1,433.8	478.9	143.1	0.0	2,360.9	420.5	34.0	1.9	0.0	118	3.0	2.9	8,979.4
1960	20.0	4,240.9	219.0	203.4	288.5	0.0	2,903.1	222.8	718.0	1.9	0.0	118	3.0	2.9	8,941.5
1961	52.8	3,714.1	268.5	76.7	136.0	0.0	2,581.0	74.0	174.0	1.9	0.0	118	3.0	2.9	7,202.9
1962	14.0	2,141.1	708.8	356.5	76.6	0.0	2,923.0	142.5	174.0	1.9	20	118	3.0	2.9	6,682.3
1963	82.6	0.0	1,475.4	783.6	199.7	0.0	3,165.9	169.2	51.8	1.9	27	118	0.0	2.9	6,078.0
1964	18.0	0.0	549.4	330.8	50.9	0.0	3,917.2	266.8	13.0	1.9	27	118	0.0	2.9	5,295.9
1965	4.1	193.1	338.9	226.9	59.0	0.0	6,200.7	83.02	10.0	1.9	28.2	118	0.3	2.9	7,267.0
1966	12.2	514.9	230.9	77.1	23.7	0.0	1,253.6	52.72	18.1	1.9	34.0	118	0.3	2.9	2,340.3
1967	20.4	648.0	284.16	148.3	14.3	0.0	2,207.6	80.64	11.8	1.9	34.0	118	0.3	2.9	3,572.3
1968	0.5	1,121.6	271.1	88.4	39.0	0.0	3,983.8	121.9	3.6	1.9	34.0	118	0.3	2.9	5,787.0
1969	27.2	699.5	52.0	119.6	9.83	0.0	3,547.4	13.63	3.6	1.9	34.0	94	0.3	2.9	4,605.9
1970	4.5	357.3	31.7	53.3	5.84	0.0	1,235.2	14.15	0.0	1.9	34.0	71	0.3	2.9	1,812.1
1971	9.0	306.5	0.89	0.1	2.7	0.0	632.1	0.65	0.0	1.9	34.0	71	0.3	2.9	1,062.0
1972	28.4	1,361.8	9.8	33.1	1.61	0.0	5.04	24.6	0.0	1.9	34.0	71	0.3	2.9	1,574.5
1973	1.0	1,398.3	58.2	79.1	3.03	0.0	53.02	15.87	0.0	1.9	34.0	71	0.3	2.9	1,718.6
1974	1.4	2,449.6	25.2	40.1	1.69	0.0	11.0	38.8	0.0	1.9	34.0	71	0.3	2.9	2,677.9
1975	5.6	2,850.0	120.9	19.1	1.25	0.0	3.51	0.68	0.4	1.9	34.0	71	0.3	2.9	3,111.5
1976	2.7	3,345.5	26.9	13.8	4.17	0.0	7.22	3.37	0.0	2.4	34.0	71	0.4	2.9	3,514.4
1977	0.6	757.61	130.0	53.4	1.89	0.0	4.73	0.61	10.4	1.9	34.0	71	0.3	2.9	1,069.3
1978	1.8	0.0	13.30	29.2	1.92	0.0	0.04	72.6	2.2	1.9	34.0	71	0.0	2.9	230.8
1979	0.8	0.0	47.23	12.4	1.5	0.0	0.06	2.84	0.0	1.9	22.0	71	0.0	2.9	162.6
1980	13.4	2.7	135.4	89.6	1.64	0.0	16.14	0.54	3.3	1.9	7.0	0.7	0.0	2.9	275.2
1981	1.3	30.1	424.7	135.7	2.10	0.0	10.01	0.75	0.0	1.9	7.0	1.2	0.3	2.9	618.0
1982	2.1	52.4	23.68	122.0	3.91	0.0	118.33	6.23	0.0	1.9	7.0	1.8	0.3	2.9	342.6
1983	6.4	130.2	45.81	41.6	3.87	0.0	82.8	1.43	0.0	1.9	2.4	5.4	0.3	2.9	325.0
1984	12.1	574.5	43.93	84.1	5.05	0.0	46.19	171.4	2.8	1.9	6.4	10.4	0.3	2.9	962.0
1985		130.1	3.33	0.22	3.42	0.0	0.06	1.12		1.9			0.3	2.9	218.7[2]
1986		0.0	3.75	0.24	3.77	0.0	0.06	1.46		1.9			0.3	2.9	43.7[2]
1987		200.1	3.29	0.18	2.09	0.0	0.37	0.36		1.9			0.3	2.9	246.9[2]
1988		90.1	1.09	0.12	0.80	0.0	0.09	0.18		1.9			0.3	2.9	97.5
Total	985.3	41,892.21	33,433.26	26,198.86	1483.88	13,272	47,164.67	2686.75	3131	68.9	596	2490.5	39.4	110.2	173,675.16

Appendix 2C. Fugitive uranium and thorium emissions from wind erosion of Waste Pits 1, 2 and 3.

	Pit 1			Pit 2			Pit 3		
Year	Exposed pit area (ft^2)	Uranium emission (kg/yr)	Thorium emission (kg/yr)	Exposed pit area (ft^2)	Uranium emission (kg/yr)	Thorium emission (kg/yr)	Exposed pit area (ft^2)	Uranium emission (kg/yr)	Thorium emission (kg/yr)
1953	4,293	0.15	--	--	--	--	--	--	--
1954	6,868	0.25	--	--	--	--	--	--	--
1955	38,633	1.4	--	--	--	--	--	--	--
1956	55,803	2.0	--	--	--	--	--	--	--
1957	60,095	2.16	--	17,781	46.4	0.014	--	--	--
1958	60,095	2.16	--	35,562	92.7	0.032	--	--	--
1959	60,095	2.16	--	35,562	92.7	0.032	0	0.0	0.0
1960	60,095	2.16	--	40,008	104.3	0.032	0	0.0	0.0
1961	51,510	1.85	--	44,453	115.9	0.036	0	0.0	0.0
1962	42,925	1.54	--	44,453	115.9	0.036	44,431	0.63	0.0
1963	17,170	0.62	--	44,453	115.9	0.036	44,431	0.63	0.0
1964	8,585	0.31	--	44,453	115.9	0.036	236,966	3.36	0.01
1965	8,585	0.31	--	22,227	57.95	0.018	266,587	3.78	0.014
1966	8,585	0.31	--	13,336	34.8	0.01	266,587	3.78	0.014
1967	8,585	0.31	--	0	0	0.0	0	0.0	0.0
1968	12,878	0.46	--	0	0	0.0	0	0.0	0.0
1969	68,680	2.5	--	--	--	--	103,673	1.47	0.005
1970	60,095	2.15	--	--	--	--	177,725	2.52	0.01
1971	51,510	1.85	--	--	--	--	177,725	2.52	0.01
1972	42,925	1.54	--	--	--	--	88,862	1.26	0.005
1973	34,340	1.23	--	--	--	--	88,862	1.26	0.005
1974	25,755	0.92	--	--	--	--	29,621	0.42	0.0
1975	17,170	0.62	--	--	--	--	236,966	3.35	0.01
1976	8,585	0.31	--	--	--	--	236,966	3.35	0.01
1977	--	--	--	--	--	--	236,966	3.35	0.01
1978	--	--	--	--	--	--	207,346	2.94	0.01
1979	--	--	--	--	--	--	177,725	2.52	0.01
1980	--	--	--	--	--	--	133,294	1.89	0.005
1981	--	--	--	--	--	--	103,673	1.47	0.005
1982	--	--	--	--	--	--	44,431	0.63	0.0
1983	--	--	--	--	--	--	0	0.0	0.0
1984	--	--	--	--	--	--	--	--	--
1985	--	--	--	--	--	--	--	--	--
1986	--	--	--	--	--	--	--	--	--
1987	--	--	--	--	--	--	--	--	--
1988	--	--	--	--	--	--	--	--	--
Total		29.2	--		892.45	0.282		41.13	0.133

Appendix 2C. (Continued) Fugitive uranium and thorium emissions from wind erosion of Waste Pits 4, 5 and 6.

	Pit 4			Pit 5			Pit 6		
Year	Exposed pit area (ft^2)	Uranium emission (kg/yr)	Thorium emission (kg/yr)	Exposed pit area (ft^2)	Uranium emission (kg/yr)	Thorium emission (kg/yr)	Exposed pit area (ft^2)	Uranium emission (kg/yr)	Thorium emission (kg/yr)
1953	--	--	--	--	--	--	--	--	--
1954	--	--	--	--	--	--	--	--	--
1955	--	--	--	--	--	--	--	--	--
1956	--	--	--	--	--	--	--	--	--
1957	--	--	--	--	--	--	--	--	--
1958	--	--	--	--	--	--	--	--	--
1959	--	--	--	--	--	--	--	--	--
1960	9,583	1.9	0.38	--	--	--	--	--	--
1961	19,166	3.79	0.76	--	--	--	--	--	--
1962	38,333	7.58	1.53	--	--	--	--	--	--
1963	43,124	8.52	1.72	--	--	--	--	--	--
1964	47,916	9.47	1.91	--	--	--	--	--	--
1965	47,916	9.47	1.91	--	--	--	--	--	--
1966	52,708	10.42	2.1	--	--	--	--	--	--
1967	52,708	10.42	2.1	--	--	--	--	--	--
1968	57,499	11.36	2.3	0	0.0	0.0	--	--	--
1969	57,499	11.36	2.3	0	0.0	0.0	--	--	--
1970	57,499	11.36	2.3	0	0.0	0.0	--	--	--
1971	57,499	11.36	2.3	0	0.0	0.0	--	--	--
1972	62,291	12.3	2.49	0	0.0	0.0	--	--	--
1973	62,291	12.3	2.49	0	0.0	0.0	--	--	--
1974	62,291	12.3	2.49	17,860	0.28	0.1	--	--	--
1975	67,082	13.26	2.68	44,649	0.71	0.24	--	--	--
1976	71,874	14.2	2.87	142,877	2.27	0.76	--	--	--
1977	81,457	16.1	3.25	53,579	0.85	0.29	--	--	--
1978	91,040	18.0	3.64	53,579	0.85	0.29	--	--	--
1979	95,832	18.94	3.83	53,579	0.85	0.29	3,240	8.26	--
1980	95,832	18.94	3.83	53,579	0.85	0.29	4,860	12.4	--
1981	95,832	18.94	3.83	53,579	0.85	0.29	8,100	20.7	--
1982	95,832	18.94	3.83	53,579	0.85	0.29	8,100	20.7	--
1983	95,832	18.94	3.83	53,579	0.85	0.29	8,100	20.7	--
1984	95,832	18.94	3.83	53,579	0.85	0.29	8,100	20.7	--
1985	95,832	18.94	3.83	53,579	0.85	0.29	8,100	20.7	--
1986	95,832	18.94	3.83	53,579	0.85	0.29	8,100	20.7	--
1987	95,832	18.94	3.83	89,296	1.42	0.48	8,100	20.7	--
1988	95,832	18.94	3.83	119,124	1.9	0.64	8,100	20.7	--
Total		394.9	79.8		15.1	5.1		186	--